STUDY OF STRATA AND SUPPORT BEHAVIOUR OF A LONGWALL MINE

A THESIS SUBMITTED IN PARTIAL FULFILLMENT

OF THE REQUIREMENTS FOR THE DEGREE OF

BACHELOR OF TECHNOLOGY

IN

MINING ENGINEERING

BY

AJIT KUMAR MAHARANA

109MN0583

Department of Mining Engineering

National Institute of Technology

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2013

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Under the Guidance of

Prof. S. Jayanthu & Prof. D. P. Tripathy

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CERTIFICATE

This is to certify that the thesis entitled,- "***Study of Strata and Support Behaviour of a Longwall Mine***" submitted by **Mr. Ajit Kumar Maharana**, **109MN0583**, in partial fulfillment of the requirement for the award of Bachelor of Technology Degree in Mining Engineering at the National Institute of Technology, Rourkela (Deemed University) is a record of original research work carried out under our supervision.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any University/Institute for the award of any Degree or Diploma.

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An assemblage of this nature could never have been attempted without reference to and inspiration from the works of others whose details are mentioned in reference section. I acknowledge my indebtedness to all of them.

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CONTENTS

ABSTRACT

The Longwall mining operation in a mechanized underground mine system that depends upon many decisions influenced by the geo-technical parameters which are often interspersed with inherent strata configurations. The present study was aimed to examine thoroughly Longwall mining operational systems in Indian geo-mining conditions with stress on studying the strata behaviour with regards to roof and floor convergence at main and tail gate road ways, analyzing the pattern of load on chock shield supports as well as simulating the mine conditions to validate the behaviour pattern observed with the data collected from the mine.

The following conclusions were drawn from the project work:

- With the advancement of the line of extraction and increase of area of exposure, the cumulative convergence increased significantly. The maximum roof to floor convergence of 42 mm was recorded in tail gate when the face position was at 150 m and a maximum roof to floor convergence of 62mm was recorded at main gate implying a greater load concentration over the main gate compared to the tail gate.

- The pressure of the rear leg was always less than the pressure of the front leg which implies a stable roof condition over the face of extraction.
- The chock shield leg pressure readings along the face indicate a higher pressure concentration at the middle section of the face where the maximum pressure observed was 380 bar after 10m of extraction compared to the adjoining sections. Peak pressures were recorded at distances of 10m, 40m, 80m, 105m and145m while minimum pressures were observed at 20m, 50m,70m,90m,115m and 125m.
- The model generated results show a lesser deformation compared to the actual field data with the exception of the deformation at 30m where a minor roof fall at the actual mine site resulted in a decreased deformation at the mine compared to the model generated results.
- An increasing rate of convergence and pressure were observed from the results of the simulated models as the seam was extracted with a maximum of 20mm deformation recorded at 60m of extraction indicating a major roof fall occurrence beyond 60m

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CHAPTER 1

INTRODUCTION

1. INTRODUCTION

To make mining operations safe and sound the study of strata behavior and support design is very essential as the complete success of the mine depends on these factors. Support design are essential in determining the type of mechanism to be practiced for better production With the emphasis more and more on environmental friendly and fast producing mode of extraction of coal longwall has grown in stature both leaps and bounds as one of the most trusted and most followed method of extraction of coal from thick seams. Mechanism of movement of the ground is very essential in understanding the strata behavior and optimum design of support system for a better efficient mine.

India ranks third in the list of largest coal producers in the world and has reserves of around 240 billion tones, with shallow coal seams that can be extracted through opencast mines gradually being exhausted, the spot light is on highly productive underground methods that can be used to extract coal at a faster rate as well as comply with the ever increasing demand of power. So bulk production as well as safer modes of extraction has become important for future needs. The most proven and efficient method as of now has been longwall technology.

Moonidih colliery was the first mine in India where mechanised Longwall was practiced for the first time in August 1978. Subsequently owing to high production rates the popularity of longwall began to increase and longwall panels were made in most mines. Singareni Collieries company Limited has been a pioneer in the field of longwall technology. Though SCCL wasn't the first to bring up longwall technology in India but the high success rate of longwall technology in SCCL mines has set a milestone for other mines to target. The production figures 3000-4000t/day they are even comparable to opencast mining methods,

This technology was first introduced in SCCL in September 1983 in GDK7/ VK7 mines and with successful completion of two faces, the equipments were shifted to GDK 11 A, where the poor strata and underrating of supports lead to failure of this method. Improved power supports were introduced in GDK 10A Incline which leads to a healthy production rate and a yearly production of about 3.5MT. Longwall technology has evolved a lot in time to the method it is now. With the increased demands now, dependency of coal mines on productive methods like longwall is bound to take a hike in years to come.

1.1 Objectives of the Project

The Longwall technology of mining is a fully mechanised system of extraction, but its feasibility depends on many geo-technical factors as well as the inherent strata conditions of the mine. This study is focused at the examination of Longwall mining technology and its scenario in India and shall concentrate to evaluate on the following areas:

- To study the strata behavior in comparison to the roof and floor convergence at main and tail gate.
- To simulation the field conditions in FLAC 5.0 software.
- To interpret the results generated from simulating the models in FLAC 5.0 to determine the strata behaviour.
- To validate the results generated against the data collected from the mine.

CHAPTER 2

LITERATURE REVIEW

2. LITERATURE REVIEW

Longwall mining technology is one of the most successful methods over the world and though relatively new method compared to some of the methods like room and pillar, but is increasing popularity with its high production rates and safety parameters. Survey of literature has been the prime priority for the development of this system of mining over the years, and research and development of various factors has been influential in its growth of popularity among different mines all over the world. This method of mining is very successfully practiced in USA, Australia as well as China which are the major contributors of coal world over. Developed countries all over the world mainly use longwall for the coal production and major development in this technology can be attributed to contributions to these nations. Though not very successful in Indian sub-continent due to varied reasons, but SCCL has been a revelation of sorts in the Indian scenario when longwall mining is being used at a large scale for extraction of coal. Many of SCCL mines use longwall and have highly contributed to India's coal production for over a decade.

2.1 Longwall Mining Method

With a typical width of around 150-400 meters, a longwall panel is about 1000 to 3000 meters long with the thickness of seam near about 2-4 meters. A longwall can be considered as a very long and wide pillar with modes of access on either sides known as "gate roads" and "tail roads". A double drum shearer is very commonly used to extract the coal from the panel and the roof at the face is supported by numerous chock shield supports. The supports are rated mostly around 4 x 800 tones which implies the roof load they can bear, these supports form a canopy around the machinery so that there is no roof fall over the machinery and the people working alongside it. The coal extraction is done by the repeated back and forth movement of the shearer drum across the coal face. The shearer cuts the coal slice by slice in each pass or cycle and a conveyor chain called armoured conveyor chain (AFC) transports the material to the bridge stage loader (BSL) where they are crushed to smaller pieces and then transported to the surface with the help of conveyor belts.

The Longwall mining has numerous advantages over the conventional mining methods which include:

- More than 80% of the resource is recovered and in some cases it can reach early 90's compared to around 60% for traditional room and pillar method.

- Hydraulic roof supports guarantee safety of miners working under the chock shield supports when the extraction is in process.
- The extraction rate in case of longwall is very high and the production per day in most mines is around 3000 tonnes.
- These allow strategic caving of the roof which results in keeping surface features intact.

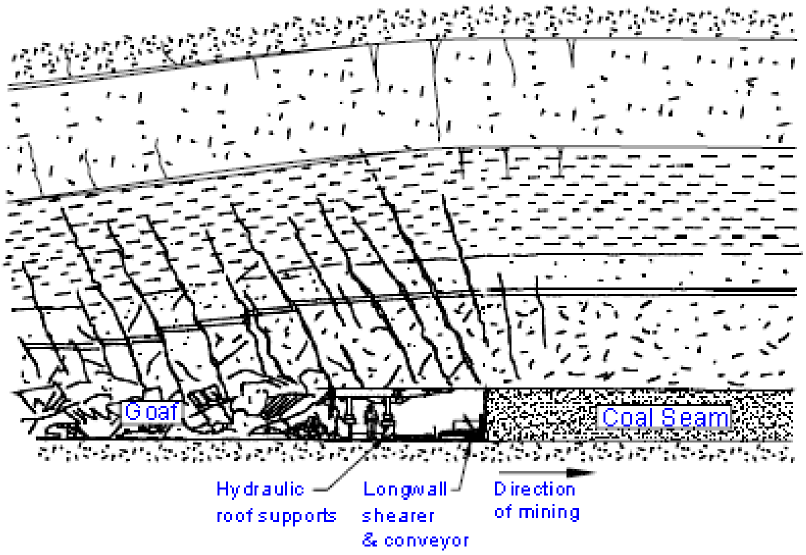

Fig. 2.1: Longwall Mining Method (Source : Issac and Smith)

2.2 Strata Behaviour

Strata control or roof control at the face is done with the help of chock shield supports which are installed at the face to protect the miners and the shearers from roof fall. To protect the gate road and tail road different systematic support rules (SSR) guidelines are followed which include installing hydraulic supports up to 30 m from face and using wooden chocks as well as w-strap with roof bolts for rest of the gate and tail roads.

2.3 Pre- Mining Stresses in the Rock

The stresses in the rock prior to mining can be classified in five categories:

- Inherent Stress
- Induced Stress
- Residual Stress
- Burden Stress
- Lateral Stress

Inherent Stress is contributed by the constituents of the rocks. The grains which compose the rock are not completely free of stress. Induced stress is the stress which is induced in rocks due to external causes like tectonic movements, hydration of and dilation of argillaceous shale. Residual stress is the stress which remains after the cause of the stress has disappeared. Burden stress is the main stress existing in the rock due to the weight of the overlying strata. Lateral stress may be caused due to orogenic forces or inability of the rocks to expand at depth under the action of burden stress.

2.4 Vertical Stress over immediate roof

- When the load in the front leg is higher, the vertical stress distribution on the front portion of the canopy is the largest and the horizontal force acts towards the face.
- As a result, there is no tensile stress in the immediate roof of the unsupported area between the canopy tip and the face line and consequently the roof will be stable
- Conversely, when the load in the front leg is smaller, the vertical stress distribution in the front portion of the canopy is also smaller.
- The horizontal force acts towards the gob resulting in development of tensile stress in the immediate roof of unsupported area, causing roof failure.

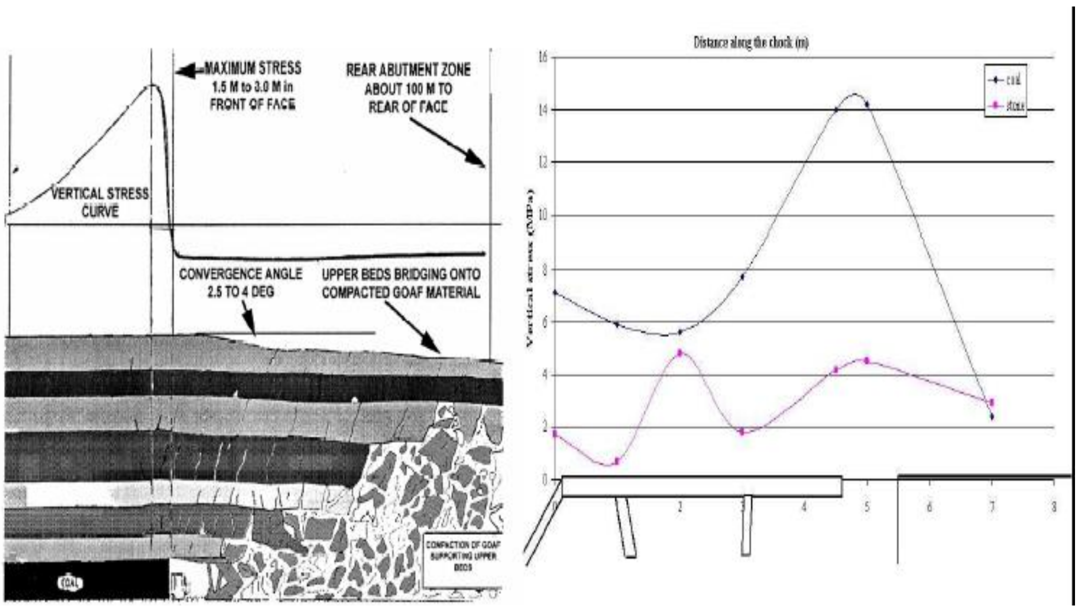

Fig. 2.2: Vertical Stress distribution (Source : Park et al)

2.5 Methods used for Support Capacity Determination

The Detached Block Theory(Wilson,1975 and Whittaker et al ,1977) assumes that waste caving governs caving height. Accordingly the roadway support system controls the block of strata below the upper beds. However it doesn't take into account of the load imposed by the bridging beds, and roadway deformation behaviour behind the face lines provides evidence of the developing nature of pack load.

The Roof Beam Tilt Theory (Smart et al, 1982) considers the bridging beds to generate the loads as the pack compacts under the downward movement of the immediate roof. The roof tilts from rib side towards the face, the amount of tilt being controlled by pack and foundation strength. Pack load may be calculated from pack stiffness value and roof bed tilt, both of which have been incorporated into appropriate equations.

Load cycle Analysis (Park et al 1992 **)** characteristic concept has been developed aimed at quantifying longwall shield-strata interaction and has been encapsulated into off-line and on-line software. The load cycle analysis concepts are a major breakthrough in understanding the interaction between a longwall shield and the surrounding strata. Before these concepts were developed the pressure signals were largely unused, simply because of a poor understanding of what they meant in terms of support-strata interaction or for that matter the integrity of the support.

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Ground Response Curves (Medhurst and Reed, 2005) plots the support pressure against the excavation convergence. If the excavation boundaries are subject to support pressure equal to the stress in the surrounding rock, no convergence will occur As the support pressure is reduced, the excavation boundaries converge and the pressure required to prevent further convergence reduces as arching and the self supporting capacity of the ground develops. A point is reached where the required support resistance begins to increase as self-supporting capacity is lost and the dead-weight of the failed ground must be resisted.

2.6 Systematic support rules

2.6.1 Approved Systematic Support Rules followed at GDK 10 A Inc Mine

The Longwall is driven with 7.0m wide with the following support system. The gallery IS supported with 1.8m length roof bolts in Seven rows with 1.0 m between the rows and 1.20 m between bolts in a row. The distance between side and the first row shall be 0.5 m. Two rows of OC/IRON/WOODEN props WILL be erected with 3.0m distance between rows and 2m between side and row. Chocks ARE erected with 3.0m interval alternate at dip and rise side so that the distance between chocks in the row shall be 6.0m and in between rows 4.0m.

Support on the face :

On face 4X 750T uprated to 800T, chock shields is provided so as to support the roof skin to skin along the whole length. Un-supported roof between face and supports not exceeding 0.60m.

Cogs are erected between the end of the chock shields and sides, where the spacing between the chock shields and the side is not sufficient to erect a cog, a row of props are erected in such a manner as to effectively prevent inadvertent entry of the work persons in to the goaf.

Support of gate roadways:

- The gate roadways shall be supported with 40T Hydraulic props up to a distance of 30m from the Longwall face in addition to the supports erected during development.
- Whenever, in addition to the above supports, conventional timber support is used in the face or gates, it would confirm to the following standards.
- The lids and wedges used for lagging on cross bars shall have a width not less than the diameter of the prop, a thickness not less than 8 cm and length not less than 0.5m.
- The timber used in the construction of cogs shall not be less than 1.2 m. in length and shall have at least two opposites sides joggled flat to provide suitable bearing surfaces.
- Props shall be set on solid floor and not on loose packing materials. They shall be kept tight against roof. These props are to be set on lose ground, a flat base piece not less than 5 cm. Thick, 25cm wide and 75 cm. Long shall be used.

2.7 Studies on Longwall Strata Behaviour in India and Abroad

A study of Ellan Colliery [6] stated that periodic loading of the supports with a period of 4-6 mining cycles was related to cantilever failure of sandstone bed, failure and well developed subsidence may not have extended to 20-35 m above the roof. The visual movements of the heavy abutment loading being distributed about the longwall block more broadly then might have been expected on theoretical grounds. Time dependent stress increases in the barrier pillar accounted for 25% of the total pillar stress. As the face passed, the horizontal components of normal stress increased in the direction of mining but were relieved in direction parallel to the face.

A case study about Tabas coal mine [7] highlights that there is a need to install strong support system to counter high ground deformation and low safety factor around the road ways. Floor heave is independent of the reinforcements in the ribs and roof and also face retreat. More roof bolts will be needed to control roof movements during face retreat.

A study on Panel 1B, JK 5 Mine [8] revealed that there is no significant influence of abutment loading even at the time of goaf settlement, which can be attributed to formation of distressing zone under the settled goaf. Deformation in the immediate roof was within safe limits for stability of workings. Intra-panel barrier pillars experienced no perceptive variation of stress indicating no adverse influence of parting under the settled goaf. The maximum stress change was observed at around 0.1 MPa, which is negligible compared to the peak front and side abutments.

2.8 Previous Studies

Lee, (1997) derived from his upper seam longwall gate roads that there are two main design flaws. One is to determine the location, magnitude and direction of stress transferred from lower seam mines and second to predict the effect of stress transferred from lower seam mines on opening stability. The relationship between predicted damage rating and gate road was established and quantified.

Madhurst (2006) examined the interplay between longwall support design geometry features, operational controls and geological features on ground response. The ground response curve as a concept meant to provide graphical representation of longwall support and strata interaction process. The approach was developed to address the requirement for a protocol longwall support evaluation and selection tool that can take account of support load influences in roof geology and support cover depth

Hosseini et al. (2001) observed that the knowledge of the stress redistribution around the longwall panel causes a better understanding of the mechanisms that lead to ground failure, especially to rock bursts. The wave seismic tomography, double difference method is employed as a local earthquake tomography. The wave velocity is assumed to be the recognized variable and it is therefore estimated in a denser network, by using geo statistical estimation method.

Forster et al.(2006) suggested that the use of Forster model to provide a practiced tool for design of longwall against water ingest rocks and redistribution of stress in a longwall working. It was designed and developed based on the understanding of surface and sub surface ground deformation on the subject side, it facilitated the development part of the mining systems capacity in dealing with unexpected geological disturbances as well as variations in site conditions.

Ramaiah, and Lolla, (2002) suggested that width and length of longwall pillars have significant influences on stress abutments, goaf formation, support requirements, surface subsidence and other fators. The face length is required to be sufficient to allow full caving, bulking and reconsolidation of the overburden strata. The goaf must be able to support the super incumbent load so that excessively large stress abutments will not form ahead of or on the longwall face. Field monitoring to verify the results obtained from modeling is necessary prior to application in the mine design.

Barczak (1992) suggested that high rating power roof supports is a prerequisite for meeting longwall support requirements under competent strata formations. However a detailed strata control and face powered support investigations are of paramount importance for assessing performance of longwall face. When a support design is selected the local conditions should be considered and capacity of the powered roof support must be selected based on the site geo mining conditions.

CHAPTER 3

NUMERICAL MODELLING

3. NUMERICAL MODELLING

3.1 Overview

FLAC[15]is a two-dimensional explicit finite difference program for engineering mechanics computation. This program simulates the behavior of structures built of soil, rock or other materials that may undergo plastic flow when their yield limits are reached. Materials are represented by elements, or zones, which form a grid that is adjusted by the user to fit the shape of the object to be modeled. Each element behaves according to a prescribed linear or nonlinear stress/strain law in response to the applied forces or boundary restraints. The material can yield and flow and the grid can deform and move with the material that is represented.

Though FLAC was originally developed for geotechnical and mining engineers, the program offers a wide range of capabilities to solve complex problems in mechanics. Several built-in constitutive models that permit the simulation of highly nonlinear, irreversible response representative of geologic, or similar, materials are available.

3.2 Problem Solving With FLAC

The problem is solved by using FLAC in the following sequence of steps :

- Grid generation
- Boundary and initial conditions
- Loading and sequential modeling
- Choice of constitutive model and material properties
- Ways to improve modeling efficiency
- Interpretation of results

3.3 Recommended Steps For Numerical Analysis In Geo-mechanics

The recommended steps for solving a real life situation can be modeled as follows:

Step 1 Define the objectives for the model analysis

Step 2 Create a conceptual picture of the physical system

Step 3 Construct and run simple idealized models

Step 4 Assemble problem-specific data

Step 5 Prepare a series of detailed model runs

Step 6 Perform the model calculations

Step 7 Present results for interpretation

3.3.1 Step 1: Define the Objectives for the Model Analysis

The level of detail to be included in a model often depends on the purpose of the analysis. The purpose is very essential to the whole execution of the model as all the parameters need to be determined and analyzed keeping in view the main objective or purpose for which this model is generated and there of executed.

3.3.2 Step 2: Create a Conceptual Picture of the Physical System

It is important to have a conceptual picture of the problem to provide an initial estimate of the expected behavior under the imposed conditions. All the considerations that will dictate the gross characteristics of the numerical model, such as the design of the model geometry, the types of material models, the boundary conditions, and the initial equilibrium state for the analysis should be predetermined. They will determine whether a three-dimensional model is required, or if a two-dimensional model can be used to take advantage of geometric conditions in the physical system.

3.3.3 Step 3: Construct And Run Simple Idealized Models

When idealizing a physical system for numerical analysis, it is more efficient to construct and run simple test models first, before building the detailed model. Simple models should be created at the earliest possible stage in a project to generate both data and understanding. The results can provide further insight into the conceptual picture of the system; Step 2 may need to be repeated after simple models are run. Simple models can reveal shortcomings that can be remedied before any significant effort is invested in the analysis.

3.3.4 Step 4: Assemble Problem-Specific Data

The types of data required for a model analysis include:

• Details of the geometry (e.g., profile of underground openings, surface topography, dam profile, rock/soil structure)

• Locations of geologic structure (e.g., faults, bedding planes, joint sets)

• Material behavior (e.g., elastic/plastic properties, post-failure behavior)

• Initial conditions (e.g., in-situ state of stress, pore pressures, saturation)

• External loading (e.g., explosive loading, pressurized cavern)

3.3.5 Step 5: Prepare A Series Of Detailed Model Runs

Most often, the numerical analysis will involve a series of computer simulations that include the different mechanisms under investigation and span the range of parameters derived from the assembled database. When preparing a set of model runs for calculation, several aspects, such as those listed below, should be considered:

i. How much time is required to perform each model calculation? It can be difficult to obtain sufficient information to arrive at a useful conclusion if model runtimes are excessive.

ii. The state of the model should be saved at several intermediate stages so that the entire run does not have to be repeated for each parameter variation.

3.3.6 Step 6: Perform The Model Calculations

It is best to first make one or two model runs split into separate sections before launching a series of complete runs. The runs should be checked at each stage to ensure that the response is as expected. Once there is assurance that the model is performing correctly, several data files can be linked together to run a complete calculation sequence.

3.3.7 Step 7: Present Results For Interpretation

The final stage of problem solving is the presentation of the results for a clear interpretation of the analysis. This is best accomplished by displaying the results graphically, either directly on the computer screen, or as output to a hardcopy plotting device. Plots clearly identify regions of interest from the analysis, such as locations of calculated stress concentrations, or areas of stable movement versus unstable movement in the model.

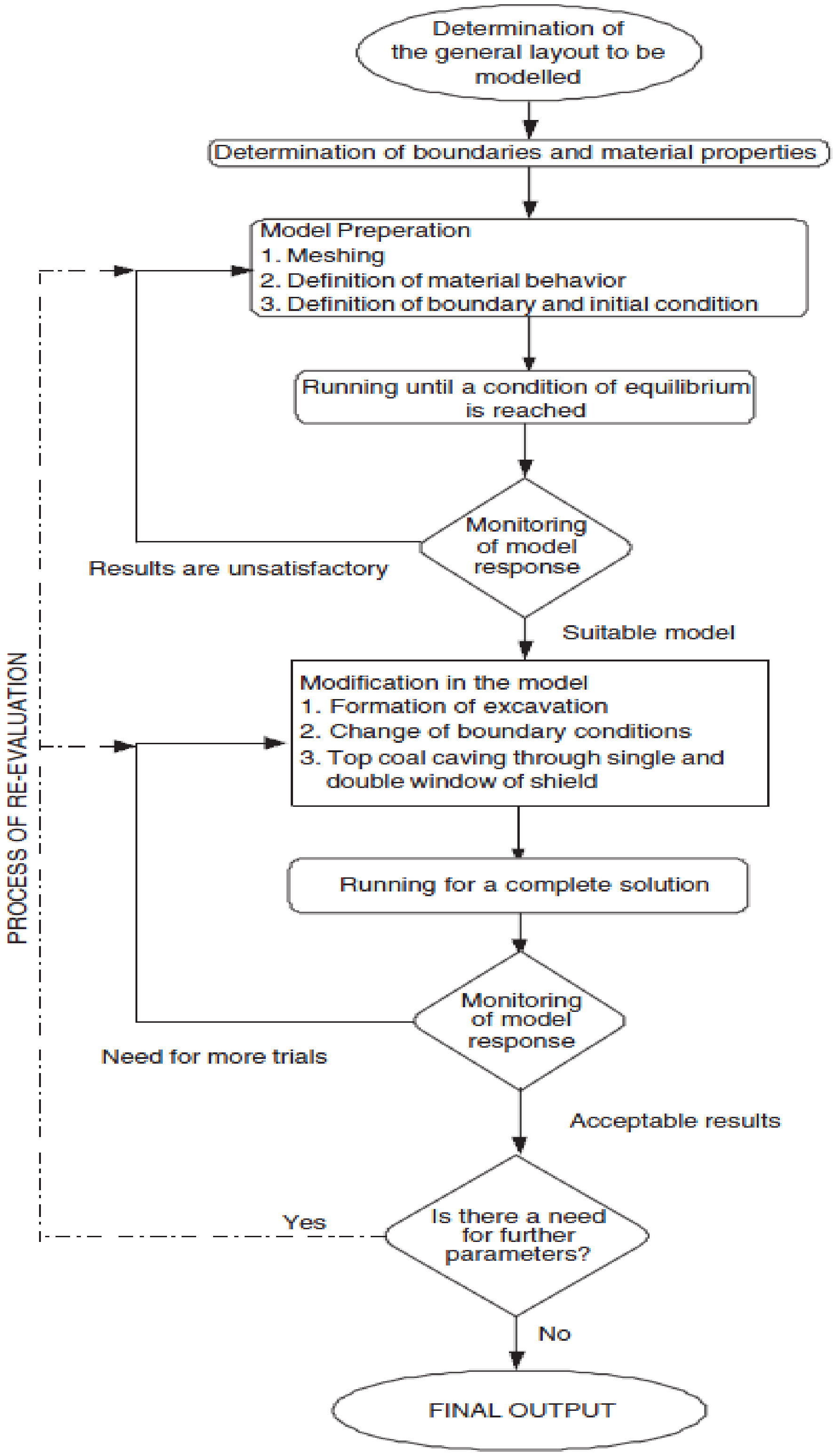

Fig.3.1 A general flow-sheet of modeling procedure
(Source: Yasitli, 2002; Unver and Yasitli, 2002; Itasca, 2005)

CHAPTER 4

METHODOLOGY

4. METHODOLOGY

Longwall mining is one of the most productive methods for extraction of coal underground. Though a very productive method there remains some scope for betterment in some specific fields. The areas for improvement includes impact of first major fall and periodic falls on the strata behaviour, convergence trend, extent of convergence in gate and tail roads, chock shield leg pressure and leg closure variance, etc. Following steps were taken to fulfill the study :

- An underground mine practicing longwall mining was selected for detailed study of project.
- Strata behavior was monitored with the electronic instruments like load cells, stress capsules and convergence stations.
- Data was collected all along the gate and tail road and even of the chock shields for database analysis.
- The Geotechnical conditions of the mine were simulated in models.
- Behavior of strata was predicted using the models generated.
- Validation of results by matching them with the data from mine to the models generated.

4.1 Study Area

For thorough study of the longwall mining conditions a mine was selected and the rest of the field study was conducted there. For field study GDK 10 A Incline of RG III Area of Ramagundam, Andhra Pradesh owned by Singareni Collieries Company Limited (SCCL) was selected. A brief description of the mine is narrated below.

GDK.10A Incline is situated at Ramagundam Area III of SCCL in Karimnagar District of Andhra Pradesh in the Godavari valley coal field. GDK 10A Mine coves an area of 855.7 Ha at present i.e. between Longitude 79^0 33’ 45” to 79^0 35’ and North latitude of 18^0 38’ 15” to 18^0 41’ 45” in the survey of India Topo sheet No. 56N/10 NW.

GDK.10A Incline was started on 06-09-1985 and it had commenced production from February, 1990. No. 1 Seam is extensively developed and the Minimum and Maximum depths are 38m and 350m respectively. The crossing and ignition point of No.1 Seam is 131^oC 155^oC respectively. The percentage of moisture and ash content are 5.79% and 32.66% respectively. The declared grade of the coal is ‘E’. The total coal reserves were 11.42 MT out of which 8.0MT was extracted. Coal reserves at GDK.10A Incline are persistent in 4 Coal seams. The seam No.1 of this mine block has been exploited through GDK.10A Incline mine and No.2 Seam is virgin. No.3 & 4 Seams are being worked by GDK.10 Incline.

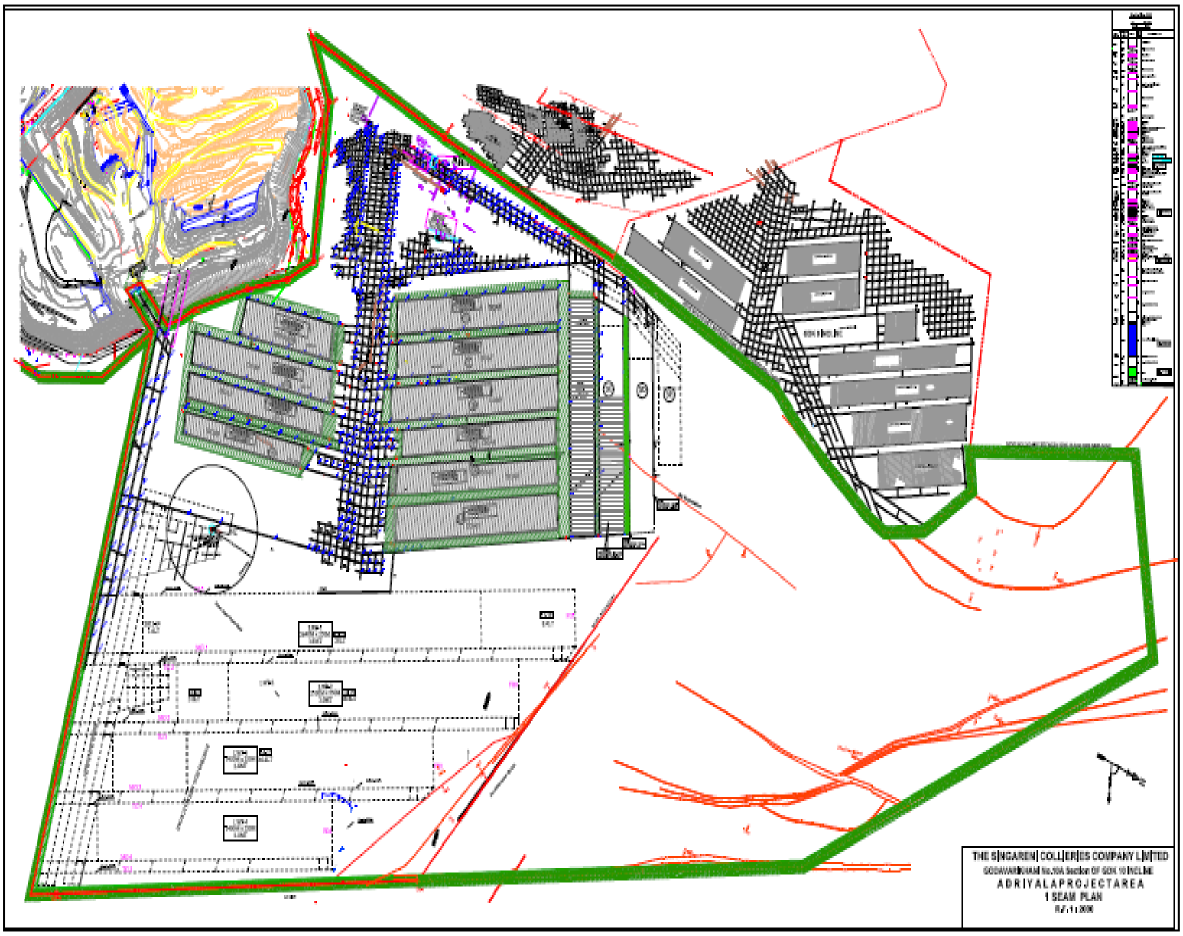

Fig4.1: Seam plan of GDK 10A Incline.

4.2 Details about the panel selected for study.

Name of the seam	:	No. 1 seam
Total thickness of the seam	:	6.5 Mts.
Average seam gradient	:	1 in 6.0
Working section	:	3.3 M along the floor
Nature of roof	:	Coal with a clay band (0.30m)
Nature of floor	:	Grey sand stone
Depth	:	Max - 310M, Min -175M
South side workings	:	Goaves of already worked out LW panels

Length of the panel	:	432.5 M
Face length	:	150 M
Gate roads	:	Main Gate – 39 Dip
		Tail Gate – 43 Dip
Supports in the face	:	4 x 800 T Chock shields (IFS)
No. of supports at the face	:	101

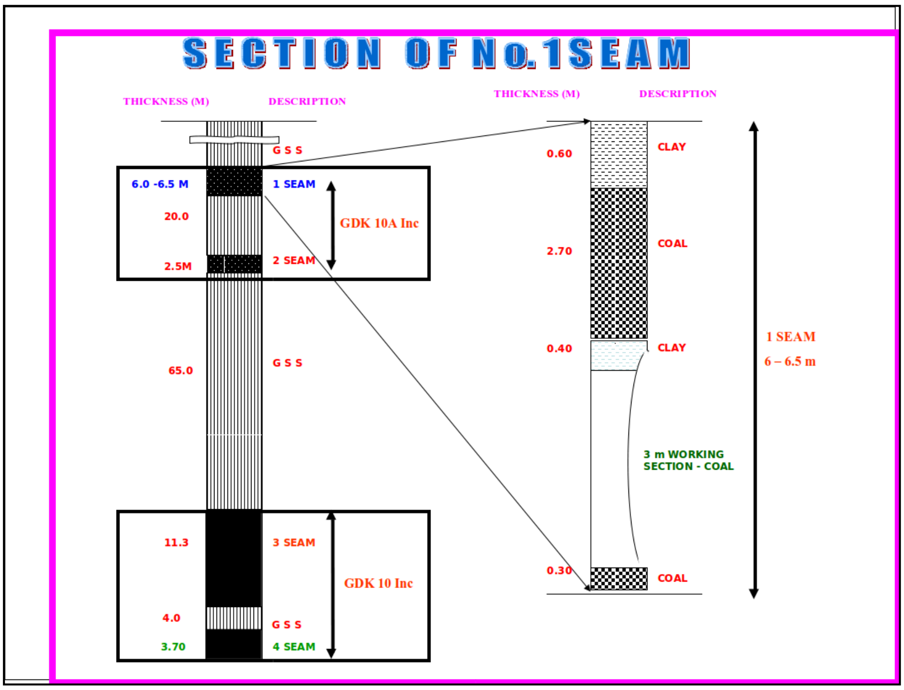

Fig 4.2 Borehole data of the GDK 10 A Inc Mine

The scheme of strata monitoring is as follows:

1. Load on supports at the face during normal and weighting periods.
2. Convergence during normal and weighting periods at the face.
3. Convergence in the gate roads.
4. Load on Individual supports installed at the gate roads.
5. Coal Pillar stress / Abutment stress.
6. Health of the chock shield leg circuits.
7. Statistical roof observation to measure r1oof flaking and cavity formation at the face during normal and weighting periods and goaf behavior.
8. Bed separation in the gate road ways.
9. Overlying strata movement in the goaf.

4.3. Instrumentation

Investigations were conducted at the mine to understand the behaviour of the strata in the longwall panel. These investigations were aimed at measuring the front abutment, and the deformation of the strata surrounding the gate roads ahead of the longwall face. These parameters were measured using geotechnical instruments such as vibrating- wire type stress cells, load cells, Tell– Tale type borehole extensometers, and convergence stations.

4.3.1 Vibrating-wire type Stress Cell

This instrument is designed for measuring unidirectional stress change in coal/rock. It consists essentially of a wire ("vibrating-wire") tensioned across a steel cylinder of 38 mm outer diameter. The wire is plucked by an electric pulse of high energy. As the stress within the rock/coal changes, the cylinder deforms, causing tension in the wire to change. The change in stress on the cell results invariation of frequency of vibration of the wire. This frequency is recorded by a digital read-out unit, and is converted into stress using calibration charts. The trend of variation of stress over the pillars or stooks indicates the extent of abutment loading in advance of the line of extraction. A bore hole of 38 mm diameter is drilled at mid height of the pillar either horizontally or slightly rising/dipping according to dip of the seam. The stress cell along with wedge and platen assembly is set in the borehole with the help of special installation tools, at a depth of 5 m.

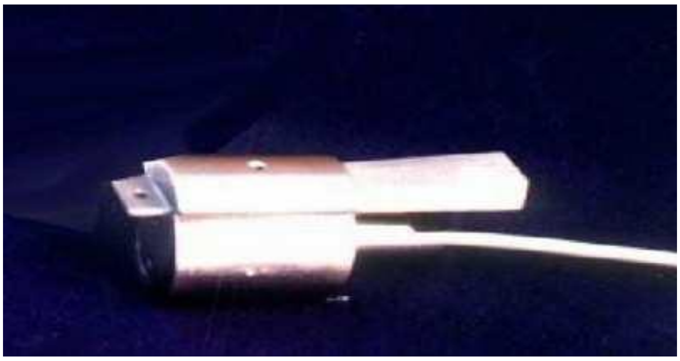

Fig. 4.3: Vibrating-wire type Stress Cell

4.3.2 Vibrating-wire type Load Cell

The load cell is a transducer working on the same vibrating-wire principle as the stress cell. It has three stretched wires housed in a metal cylinder, which are plucked by an electric pulse of high energy. Changes in the load exerted on the cell cause changes in the length of the wire, resulting in variation infrequency of vibration of the wire. As the load increases, the frequency decreases and vice-versa. This frequency is measured by a digital read-out unit, and is converted into load using calibration charts. Efficacy and adequacy of the support system can be inferred on the basis of these load cells. The load cells were installed over the hydraulic props to monitor the change in load over the props during the extraction. They were installed in the gate roads at an interval of 15 m from the face, and they were shifted with the retreat of the face line.

Fig. 4.4: Vibrating-wire type Load Cell

4.3.3 Convergence Monitoring

Telescopic convergence indicator is used for monitor the roof-to-floor convergence in mines. It is a simple instrument consisting of a graduated rod(scale) fitted in a telescopic pipe. It has a least count of 1 mm, and the telescopic movement is for a length of 2 to 4 m. The measuring points ("reference stations") are metal rods grouted in the roof and floor. Measurements are taken by stretching the telescopic rod between the reference points, and reading the graduations on the rod. These indicators are useful for understanding the roof to floor closure in the gate roads at various stages of extraction.

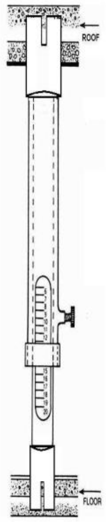

Fig. 4.5: Telescopic Convergence Indicator

Table 4.1: Comparison of Different Instruments

Instruments	Application	Cost	Advantage	Disadvantage
Telescopic Convergence Rod	To measure convergence of galleries	Rs. 3,900	Easy to use	Not Accurate
Electronic Load Cell	To measure load on supports	Rs. 12,000	Continuous monitoring	High cost
Mechanical Load Cell	To measure load on supports	Rs. 5,500	Direct display	Manual reading
Tell-Tale Extensometer	To measure bed separation	Rs. 12,000	Multilayer monitoring	Manual reading
Vibrating Wire Stress Meter	To measure stress change	Rs. 80,000	Auto data logging	High cost

4.3.4 List of instruments in longwall panel no. 3D

1. Telescopic convergence Indicators at every 5 m interval in both the gate roads roof to floor convergence.

2. Vibrating-wire stress cells 260 m – MG, 370 m – MG, 250 m – TG, 340 m – TG, change in stress over pillar.

3. Vibrating-wire type load cell at every 10 m interval in both gate roads *. Change in load over the supports.

(* shifted with the retreat of the longwall face)

4.4 Strata Control Observations

Tto understand the geo-mechanical behaviour of the strata in the gate roads and in the face. These observations were aimed at measuring the location and magnitude of the front abutment, and the deformation of the strata surrounding the gate roads, and load on supports ahead of the longwall face. Four vibrating wire type stress cells were installed, a continuous convergence recorders and convergence points, and load cells were installed in the Tail Gate and Main Gate . The location of these instruments is shown in Figure 4.6.

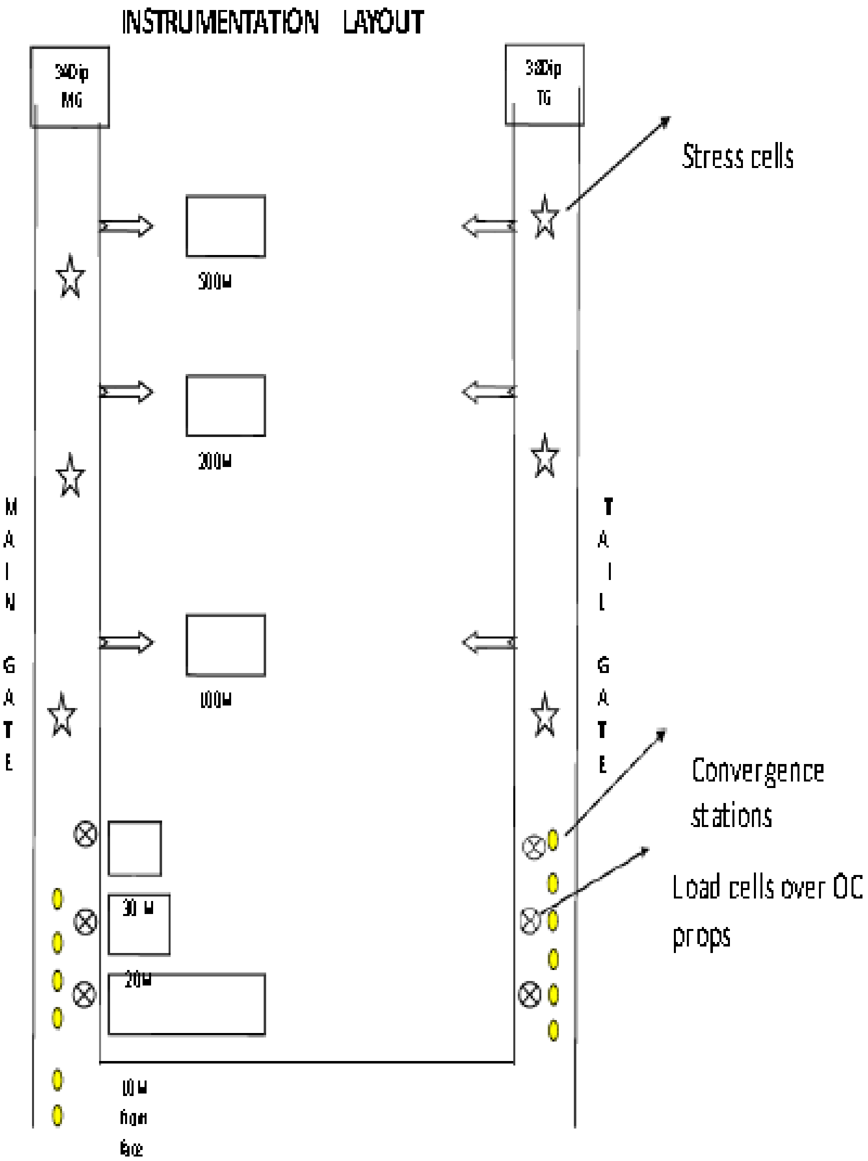

Fig. 4.6 : Instrumentation layout for Longwall panel 3D

Monitoring at the face:

i) Load on supports: Variation of the load on the supports at the face is monitored by pressure gauges installed in each leg circuit. The pressure gauge reading is taken once in every day. During most of the weighting periods the **supports at the mid zone (C30 to C80) experienced weighting** and few chocks subjected to yielding. Main weighting observed after a retreat of 78.1m and after the main weighting periodic weightings occurred at regular intervals. The periodic weighting interval varies from **10m** to **20m**. The highest observed is **19.35** on 15/1/2013

ii) Convergence at the face: Convergence at the face was measured by means of telescopic convergence indicators and leg closing is also measured with the help of Dial gauges. It shows that there was no significant leg closure and face convergence observed. Maximum **convergence found at the mid face(Between C51 and C52) is 34 mm/m** during weighting period.

Gate road ways monitoring:

Gate roadways are supported with 40 T open circuit hydraulic props. The props are set in two rows at 0.5 M interval up to 20 M from the face in both the Gate road ways. The efficiency of the supports is monitored by measuring load variation on the OC props and convergence of Gate road ways.

i) Load on the OC props: Variation of load on OC props is measured by installing load cell on the prop. Four load cells were installed at an interval of 10 m in main gate road from the face. The load variation in the load cells is measured once in every day as face progresses. Only marginal increment of load on the OC props observed. Increase of **load on OC props observed between 5Te. to 9 Te**.

ii) Convergence of the Gate road ways: Tail gate road way monitored for convergence for 70 M from the face by means of telescopic convergence indicators. The convergence stations are fixed at 10 M interval. Convergence measurements are taken once in every day. Abnormal convergence was not observed during weighting periods and normal periods.

Perceivable **Convergence in Gate roads starts 20 m to 10 m ahead of the face** and as the face approaches the point convergence increases gradually.

4.5 Sequence of Modeling

1. Development of the total seam layout at depth of 237m with the coal layer 6.5m high and a extraction height of 3.3m.
2. Development of one opening with a width of 5m at 445m.
3. Development of advancing longwall face with a difference of 15m upto a position where major fall occurs and simulation is not possible.
4. Installation of chock shield supports with parameters as:
   Compressive strength = 9.7Mpa
   Stiffness = 0.5mm per ton

The model is fixed along x- direction whereas the movement along y- direction is allowed. Along the two edges a typical roller type boundary condition are given as parameter. To estimate the in situ stress the following formula is adopted and the horizontal and vertical stress are simulated.

$$\text{Vertical stress} = \rho \times H$$

$$\text{Horizontal stress} = 3.75 + 0.015\, H$$

Where, ρ = specific weight of the overlying rock mass and

H = depth cover

Gravitational loading is simulated by the model itself . To generate pre-mining conditions before adding the mine openings to the input, the model goes through an initial analysis to generate the in situ stresses. The displacements are reset to zero and the longwall openings are added to the model and the simulation is executed so as to obtain a negligible unbalanced force. The model is executed to the following coal and sandstone parameters. Table no. 4.2:

Table 4.2: Properties of coal and sandstone

Property	Coal	Sandstone
Bulk Modulus	3.67 GPa	6.67 GPa
Shear Modulus	2.2 GPa	4.0 GPa
Density	1430 kg/m^3	2100 kg/m^3
Tensile Strength	1.86 MPa	9.0 MPa
Cohesion	1.85 MPa	6.75 MPa
Friction Angle	30^0	45^0

CHAPTER 5

FIELD INVESTIGATION

&

DATA COLLECTION

5. FIELD INVESTIGATION AND DATA COLLECTION

To form the data base, the information of Longwall mining method had been collected and processed through some stages. The respective mine is visited and experience is gained on the system of operation. Data have been collected from instruments installed in the BG panels and through log books and registers of the mine concerned. The data has been checked and authenticated by the strata control officers of those mines.

Data is collected from office records maintained daily shift wise basis. Different strata monitoring instruments and their functions are taken from manuals supplied by manufacturers. The data of natural falls, induced blasting etc. also collected from mine records and they are checked with respective mine strata monitoring in charge. Again the data collected are verified at Regional Strata Control Cell. The strata monitoring data and different information collected from Blasting Gallery panel is synthesized to evaluate the behaviour of strata.

5.1 Strata Behaviour Observations In Longwall 3D, GDK 10 A Incline, SCCL

Geological and Mining Conditions:

The longwall panel no.14 is situated in front the fault crossing at 206 m of 3D panel to the already extracted longwall panel no.13 i.e 3D1, as shown in Figure 1. The present panel is in the north side. The longwall workings are in the 6 m thick no. 1 seam. The seam is dipping at about 1 in 6; the depth of the workings is 187m minimum and 260 m maximum. A representative borehole section is shown in Figure 2. The longwall face is laid out along the dip-rise. The Tail Gate is the top gate road, and the retreat direction is along the strike.

The 6 m thick seam is being worked in the middle section to a height of about 3 m, leaving 2 m thick coal in the immediate roof. It is overlain by a 0.8 m thick clay band, and the thicker and stronger members of medium grained white sandstone forms the main roof.

The longwall equipment consisted of a double ended ranging drum shearer, with chainless haulage, mounted on armoured face conveyor. The roof is supported by 4 x 750 t Chock Shield type powered supports provided with face sprags.

Strata Control Investigations:

Investigations were conducted at the mine to understand the geo-mechanical behaviour of the strata in the gate roads and in the face. These investigations were aimed at measuring the location and magnitude of the front abutment, and the deformation of the strata surrounding the gate roads ahead of the longwall face. Five multi-point bore hole extensometers ("Tell Tales"), a continuous convergence recorders and convergence points were installed in the Main as well as in Tail Gate. The location of these instruments is shown in Figure 4.6.

The peak front and side abutments were already measured as part of some earlier projects for two panels in this mine and for two panels in the adjacent GDK 9 Incline. Therefore, it was decided that stress measurements need not be carried out again.

Gate Road Convergence

The continuous convergence recorder was installed to measure the convergence of the Tail Gate. As the face neared its position, the instrument was shifted ahead by about 10 m. The information obtained from this instrument at various locations is plotted against face position in Figures 4.6.

It can be seen from Figure 6 that, at the first location of the instrument (522 m position in the Tail Gate), the total convergence of the gate road was only about 5 mm which is not significant. However, the rate of convergence increased rapidly when the face was within 20 m of the instrument.

The total convergence of the gate road at the 540 m position is only about 2.5 mm which is quite negligible. However, as in the case of the earlier location, the rate of convergence started increasing rapidly when the face was about 24 m away from the instrument.

When the instrument was set at 571 m position, a total convergence of about 2.5 mm was recorded. Here also the rate of convergence increased rapidly when the face was within 20 m. Subsequently, the instrument was shifted to 609 m, 640 m, 677 m and 710 m positions.

5.2 Investigation of Support Performance

The performance of the chock shield type powered supports is crucial to the successful operation of the longwall face. This performance was investigated by separately measuring the closure of and the pressure changes in each individual leg of the powered supports.

The leg closure and pressure measurements were conducted on Chock nos. 24, 48 and 72. Chock no. 48 was in the center of the face and Chock nos. 24 and 72 were spaced at equal distances on either side of the central chock on the Main Gate side and Tail Gate side, respectively.

Method of Monitoring

The closure of each individual leg of the chock shield was separately measured using four Magnetic Leg Closure Indicators of the dial gauge type. These were accurate to 0.01 mm, and had a total travel of 30 mm. Whenever the closure of the legs exceeded 30 mm in the same cycle, the indicators were reset. The reset operation was almost instantaneous and there was no loss of information.

The pressure of the hydraulic fluid in the legs of the powered support was measured using the pressure gauges provided on the powered support. The pressure of both the rear legs was measured by only one gauge.

Each measurement cycle commenced immediately after the chock was advanced and reset during the mining cycle. One Magnetic Leg Closure Indicator was attached to each leg of the chock shield and the initial reading was noted down, along with the clock time. Simultaneously, the setting pressure of the legs was also recorded.

As the cutting operation continued, the closure indicators and the pressure gauges were regularly monitored. The frequency of the readings was increased or decreased depending upon the rate of movement and the mining activity. After the completion of the cut, the measurement cycle ended when the chock was ready to be lowered.

The observations were undertaken in 11 measurement cycles, during which the face retreated by nearly 50 m. The measurements were done on a shear-by-shear basis.

5.3 Weighting Details

First local fall occurred after a retreat of 16.25m. Main weighting observed after a retreat of 53.00m and after the main weighting periodic weightings occurred at regular intervals. The periodic weighting interval varies from 10m to 20m and average weighting interval is 18.45m. The details of the weightings during the last quarter are given below

S.No.	Weighting	Date/Shift	Avg. retreat	Area of expo.	Observations
1	Local	7-9-12 / PRE	15.4m	1652.75 m^2 (10.75x154.20)	- C70 to T.G entire stone roof fallen in the goaf (up to 1m thick of stone). - No bleeding, no spalling of face - No water seepage in the face.
2	Local	24-9-12 / PRE	36.6 m	2621.40 m^2 (17.00x154.20)	- C45 to C98 COAL roof behind the chock shield fallen in the goaf (up to 1m thick of stone). - No bleeding, no spalling of face - No water seepage in the face. - Stone of 5-6 m fallen in goaf.
3	Local	28-9-12 / III	52.5m	4001.49 m^2 (25.95x154.20)	- C02 to C22 stone roof fallen in the goaf (up to 1m thick stone). - No bleeding, no spalling of face - No water seepage in the face. - Fall ocoured in midpoint causing rapid airflow to c65
4	Local	06-10-12 / III	58m	10006 m^2 (39.40x154.20)	- C50 to C80 stone roof fallen in the goaf (up to 1m thick). - Sounds heard in the goaf 1.00-2.00 a.m. - Sounds in goaf observed up to tail gate1.5-2.0m stone fallen 10m behind t.g chok.
5	Goaf	09-10-12 / III	61.85m	10633 m^2 (68.95x154.20)	- Stone fall at C95-C50(1m diagonally behind chock) - Load observed in choks C45-C80.PRESSURE(350.38) - Face spalling 1-1.5m infront

					of canopy observed from C44-C65
7	MAIN weighting	19-10-12 / P, I, II, III	78.1M		- Weighting observed from C55 to C73 - Bleeding of supports C58 to C83 - Face spalling from C49 to 59 and C65 to 74. - Water seepage C48 to 55.
8	Periodic weighting	27-11-2012 / P, I, II, III	95.2M		-Bleeding of suppots from C55-71 - Face spalling from C51 to 54 - Water seepage C59-62,67-69,76-81 and C98 to 101.
9	Periodic weighting	16-12-12 / P, I, II, III	122.35 M		- 1 M slice slided and touched chok canopy - Water seepage C13-18,29-33,37-40and77-82c. - Bleeding of supports C48-C68 - Face spalling from C10-C70. - weighing zoneC40-60 above300-
10	Periodic weighting	05-01-13 / P, I, II, III	163.5		- Breaker line formed infront of canopy at C45-52&C62-67, - Sounds observed in goaf at 1.15 p.m. - Weighting observed from C26 to C76 - Bleeding of supports C48-C52 - Face spalling from C50-55, C80-80. - Water seepage C72 to 81
11	Periodic weighting	18-1-13/ P, I, II, III	188.5		- Weighting observed from C30 to C70 - Bleeding of supports C50 to C74 - Face spalling from C12 to 20 and C75 to 79

12	Periodic weighting ends	30-01-13 / P, I, II, III	181.2		- Slip observed in roof at c62 infront of canopy causing 30 cm cavityC61-C64. - Weighting observed from C10 to C20,C55-C75. - Water seepage C57 to 66,81-88. Face spalling from C35-48,C62-66.

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5.4 Cumulative Convergence readings recorded at main gate

Fig 5.1 : Convergence readings @ 150 m

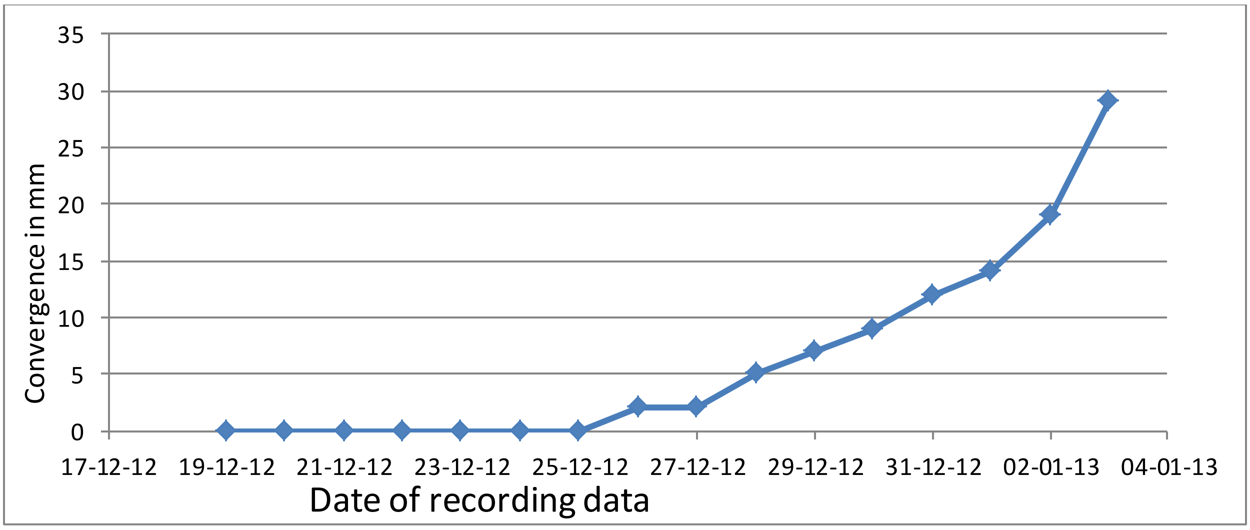


Fig 5.2 : Convergence readings @ 160 m

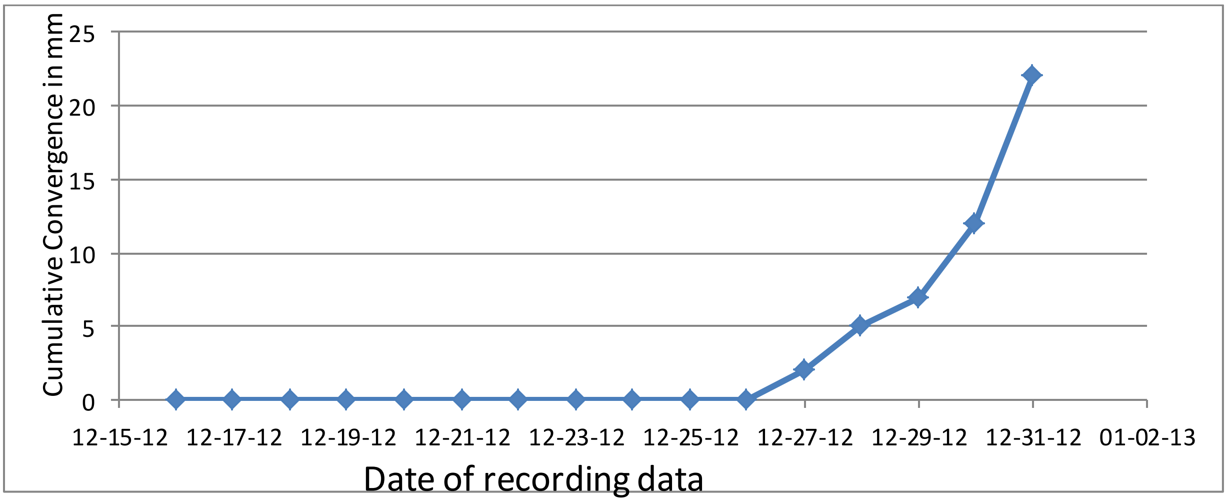


Fig 5.3: Convergence readings @ 170 m

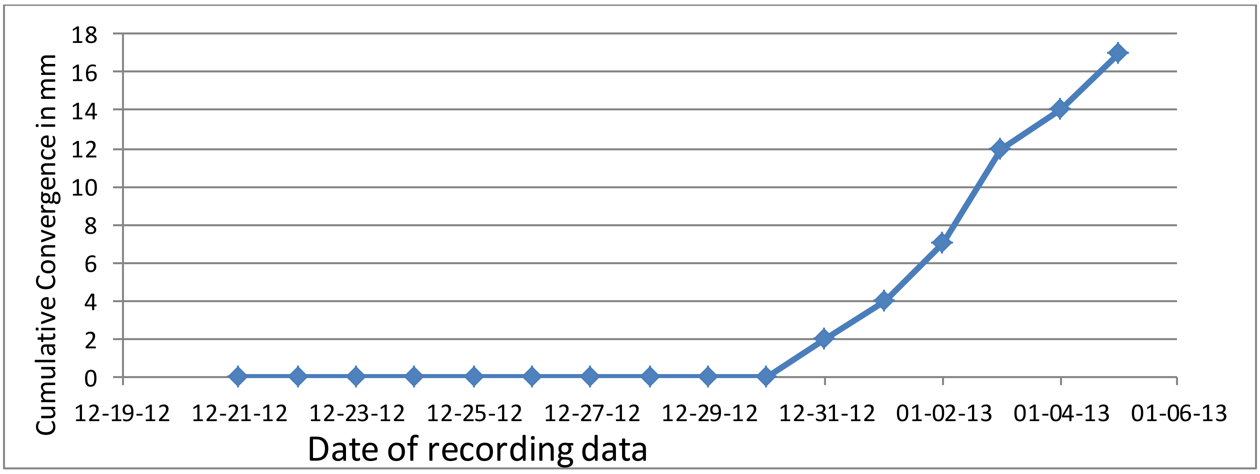


Fig 5.4: Convergence readings @ 180 m

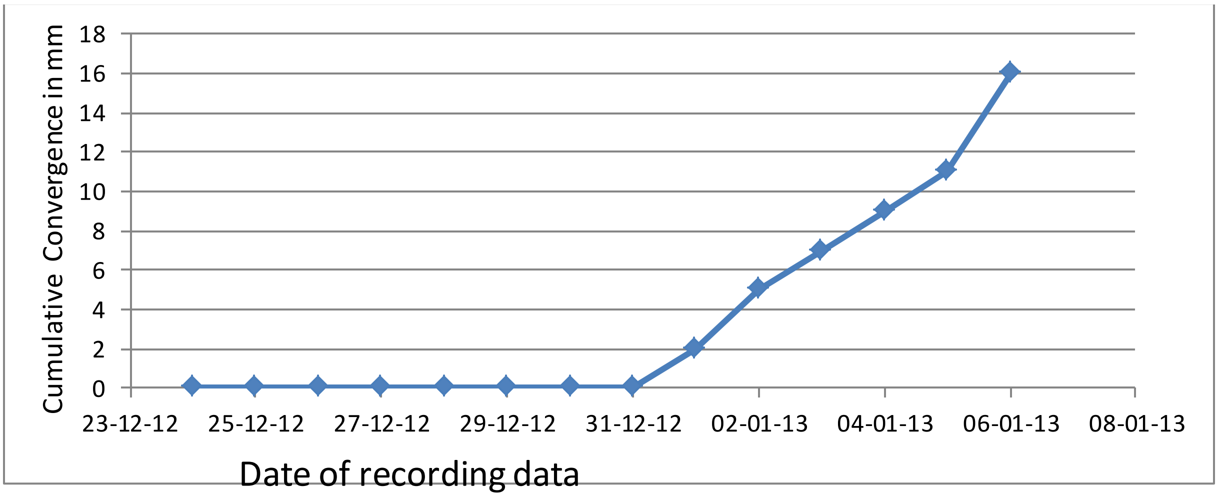


Fig 5.5: Convergence readings @ 190 m

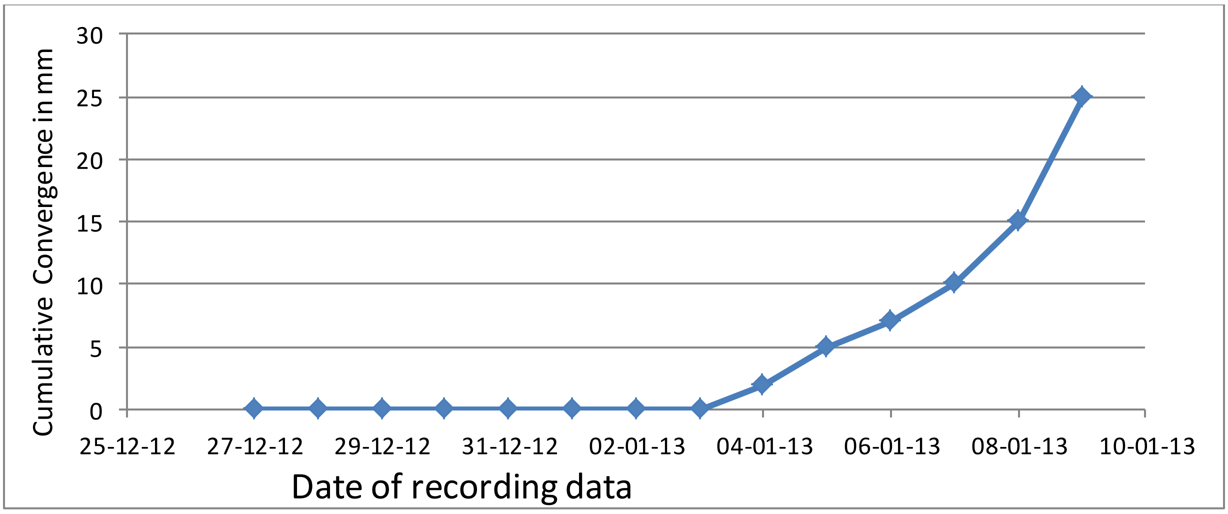


Fig 5.6 : Convergence readings @ 200 m

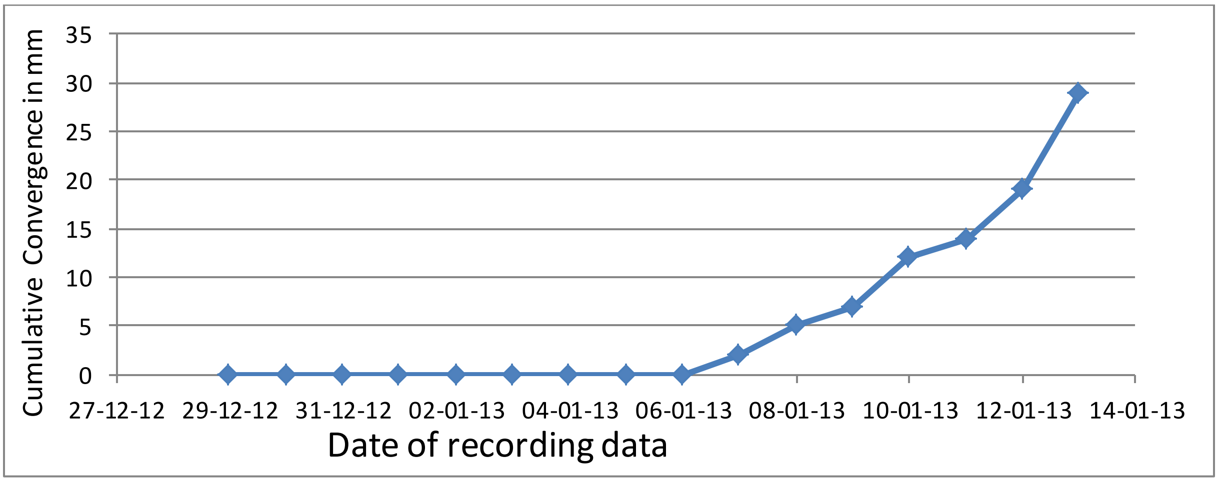


Fig 5.7: Convergence readings @ 210 m

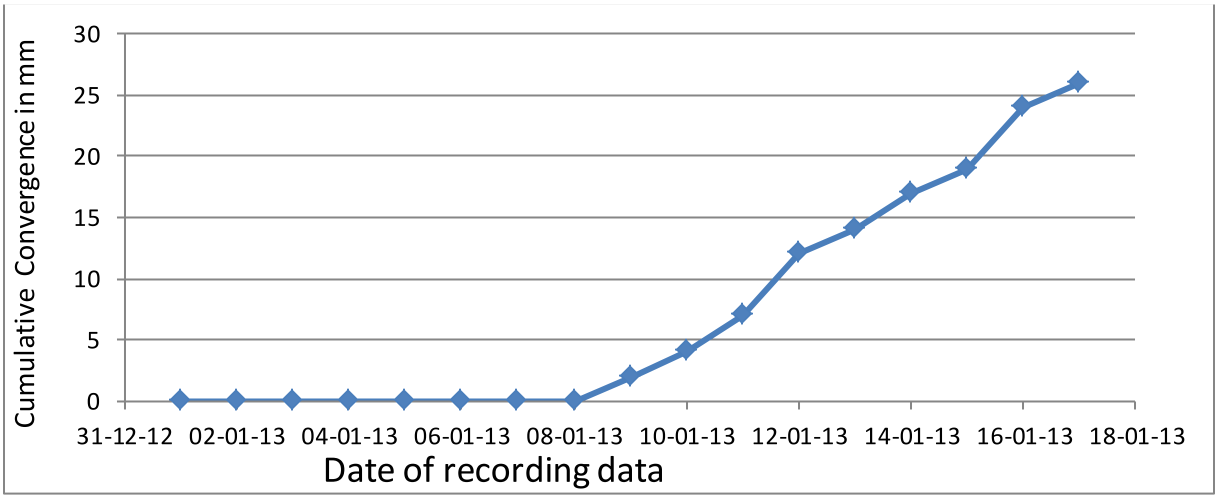


Fig 5.8: Convergence readings @ 220 m

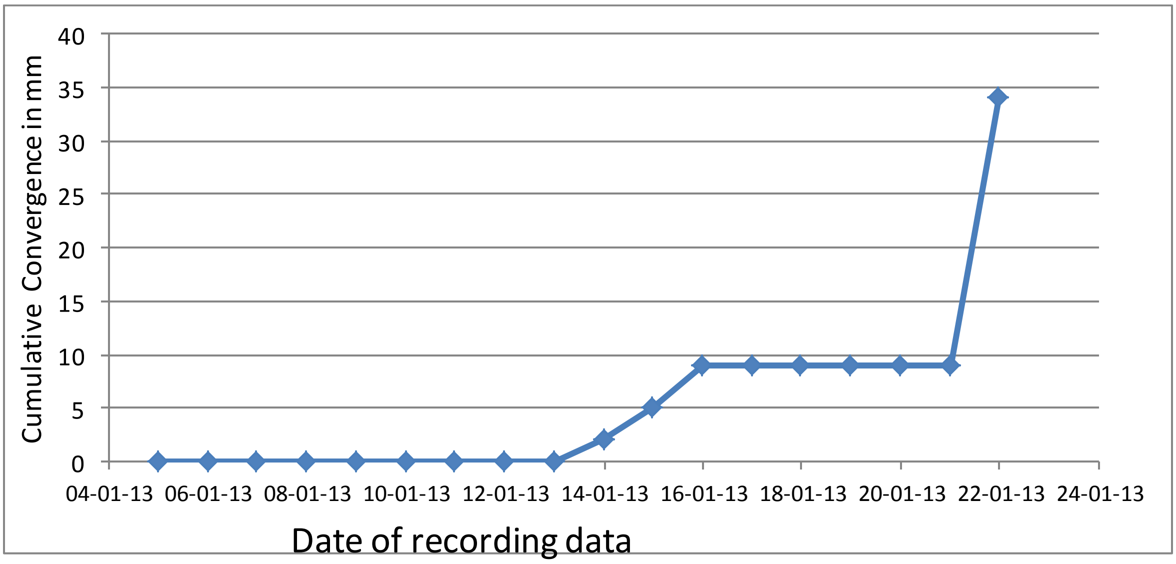


Fig 5.9: Convergence readings @ 230 m

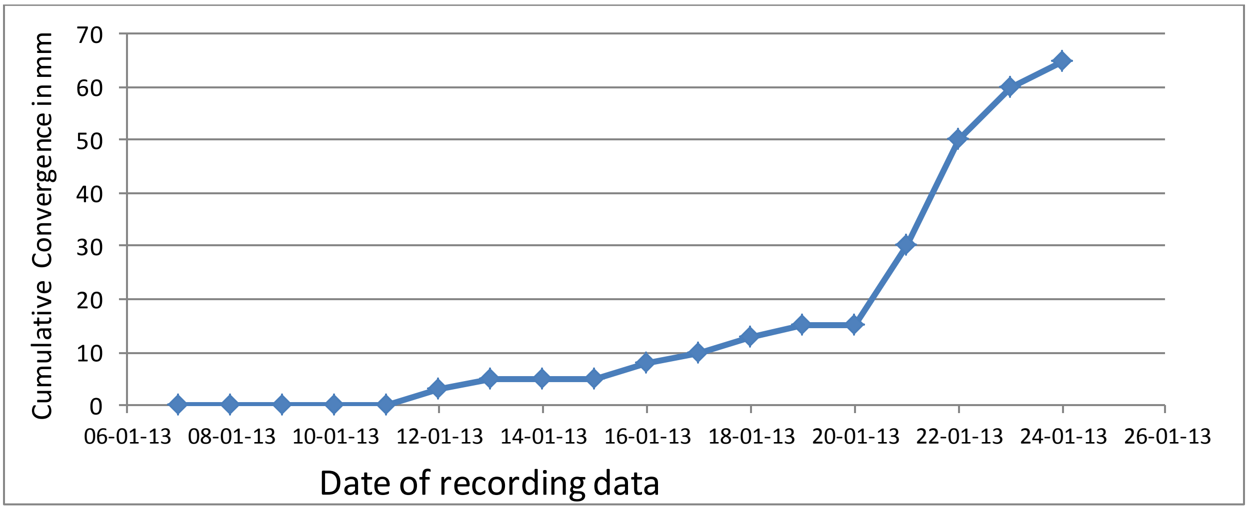
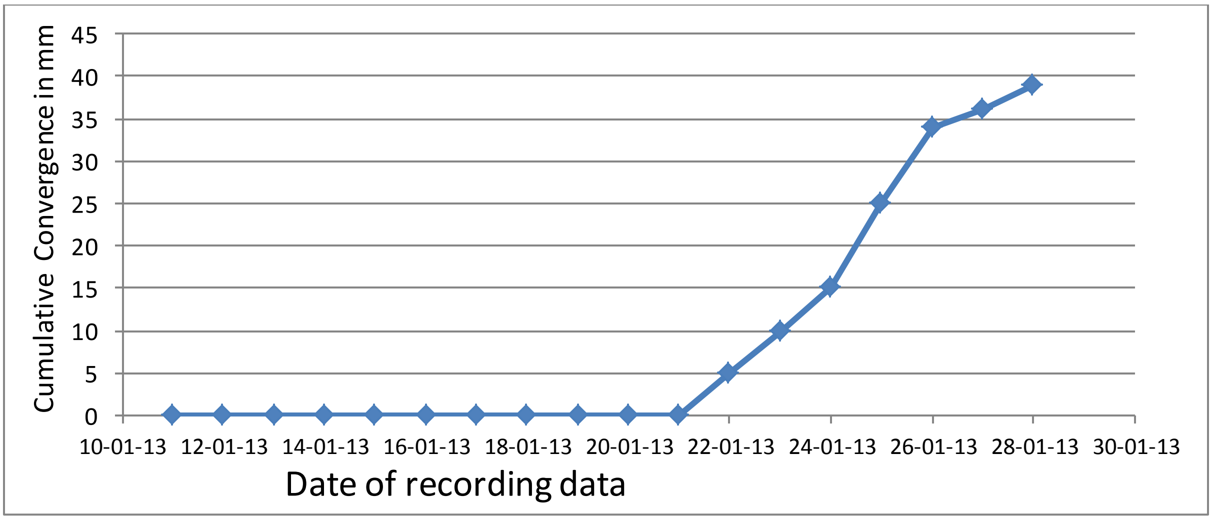


Fig 5.10: Convergence readings @ 240 m



Discussion

It was observed that there is a increase in the convergence readings as the face retreats nearer to the convergence measuring stations. The convergence reading recorded at main road varies between 25mm to 35mm before they are destroyed by the retreating face. At initial stages no convergence is observed as the face is located at a larger distance from the station to cause any change in convergence. As it gets closer to the station the convergence readings can be noted to show a steady rise. It has been observed that the reading is maximum at 240m where the reading before being disturbed is 62mm. Anomalies have been observed at station 220 m where a stagnant reading had been observed due to the damage caused to the station . After being replaced it shows a regular increase in convergence with retreat of the longwall face.

5.5 Cumulative Convergence Readings of the Tail Gate

Fig 5.11: Convergence readings @ 150 m

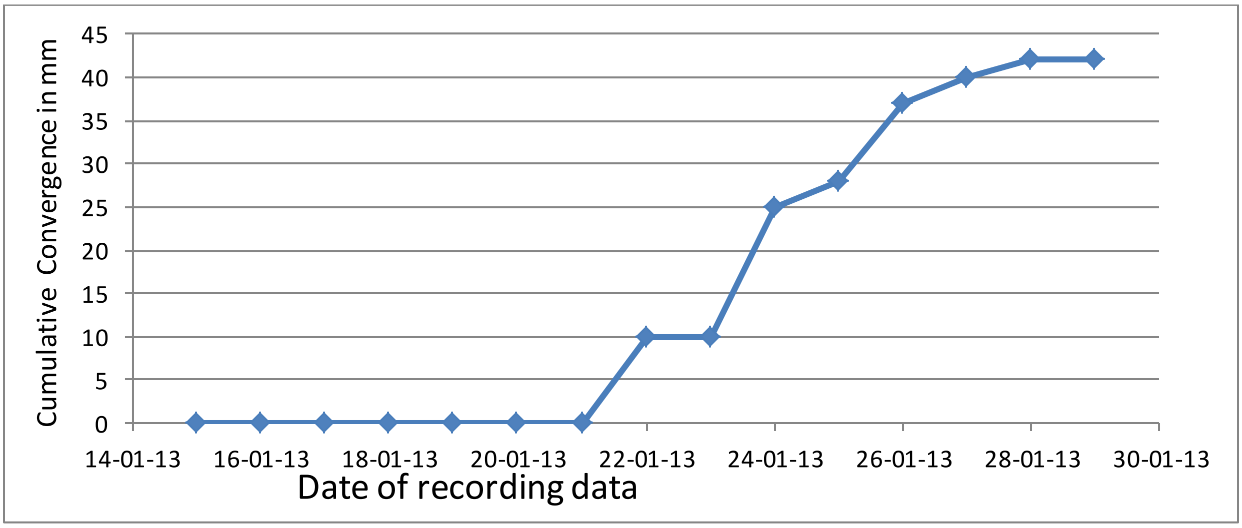


Fig 5.12: Convergence readings @ 160 m

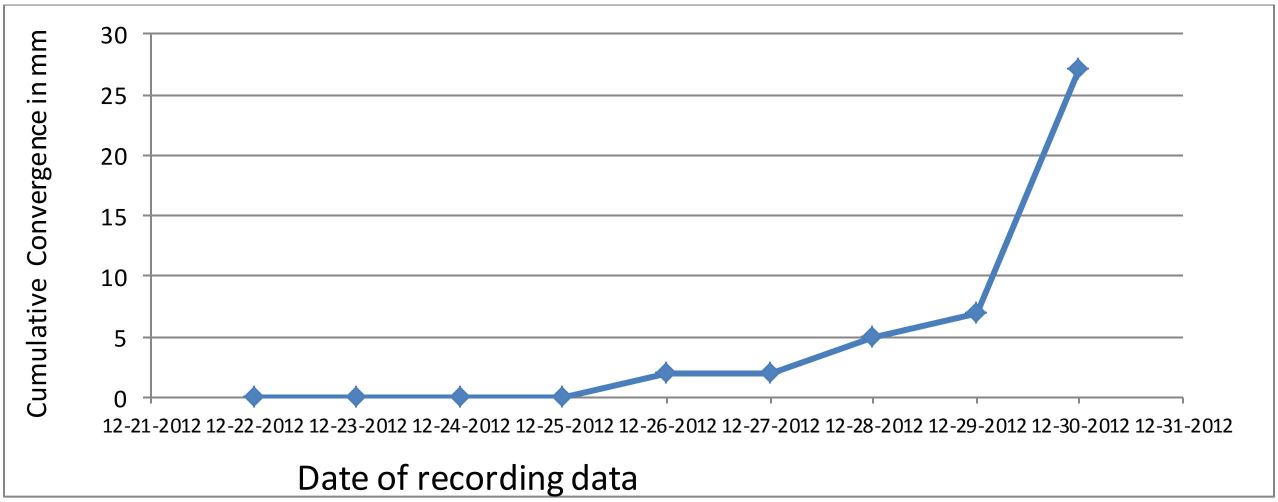


Fig 5.13: Convergence readings @ 170 m

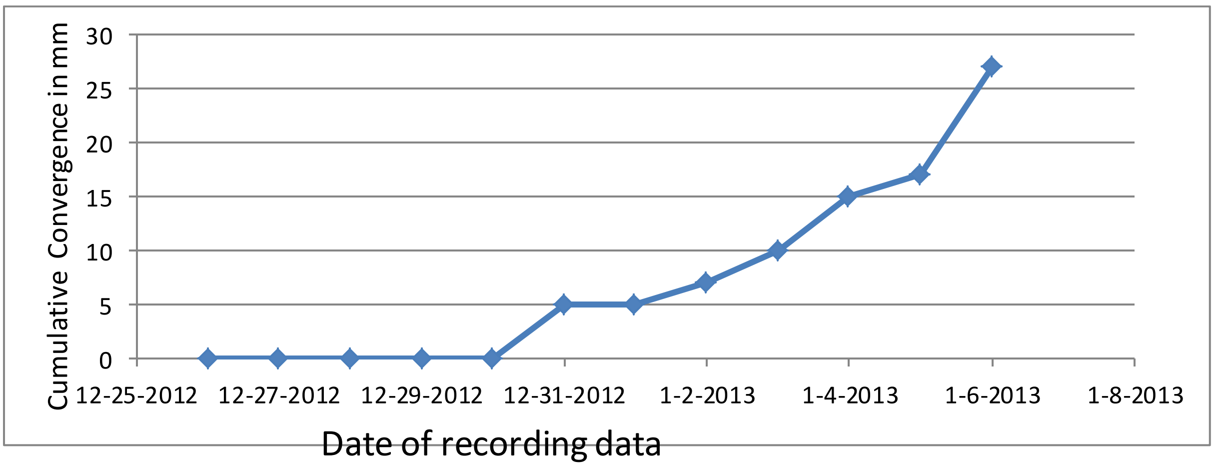


Fig 5.14: Convergence readings @ 180 m

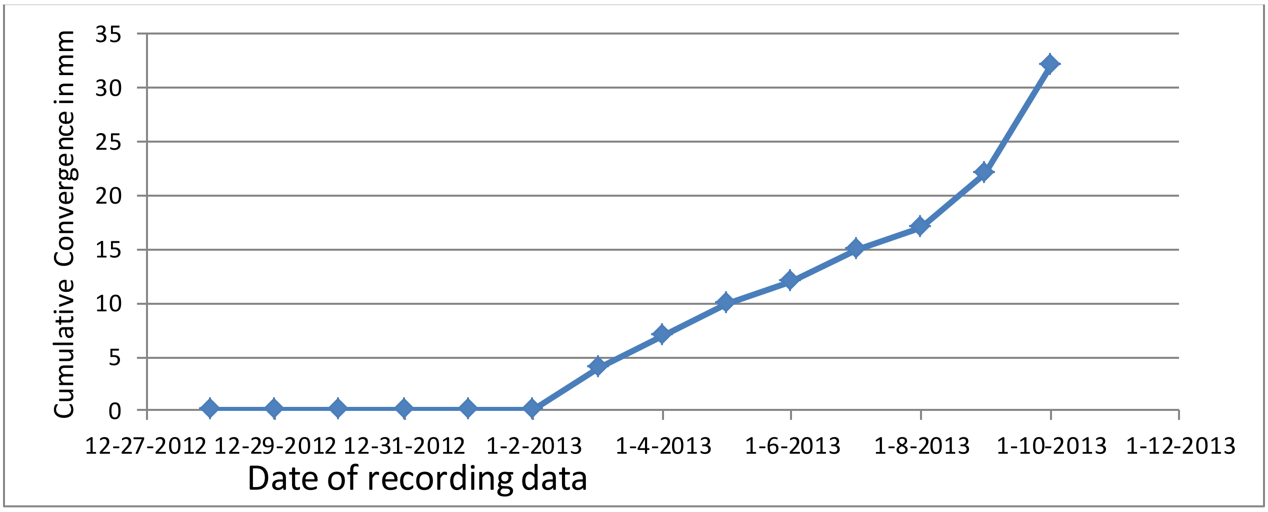


Fig 5.15: Convergence readings @ 190 m

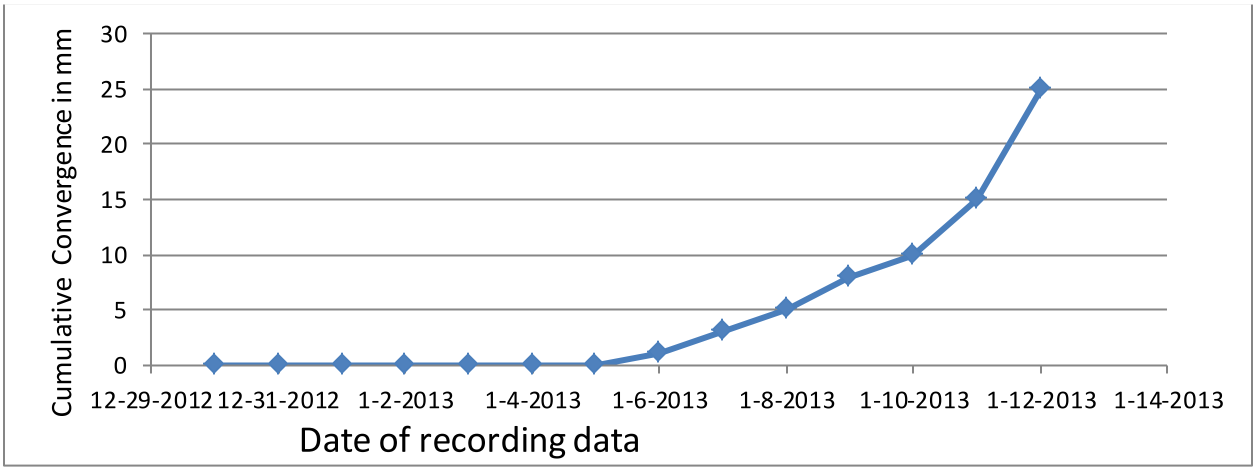


Fig 5.16: Convergence readings @ 200 m

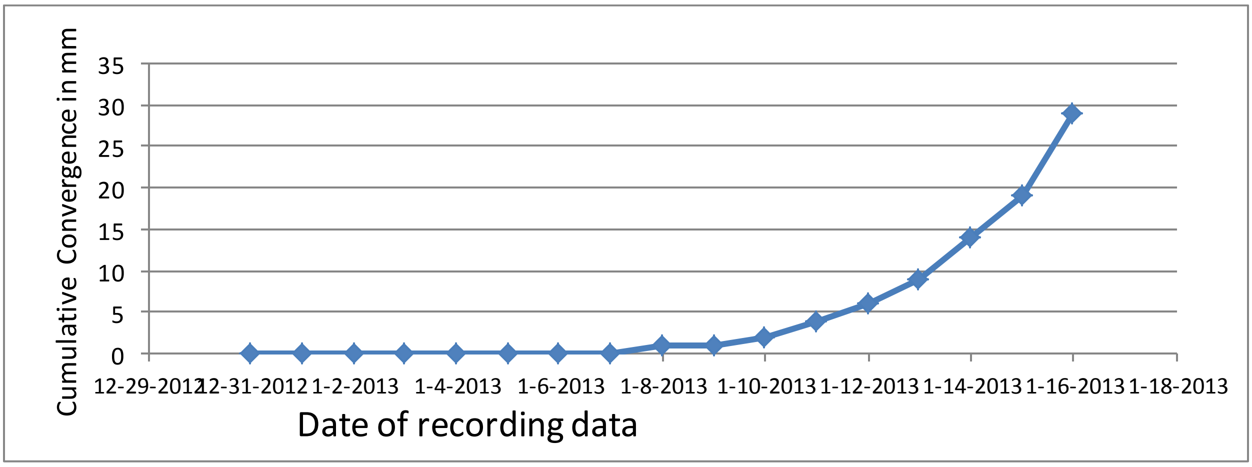


Fig 5.17: Convergence readings @ 210 m

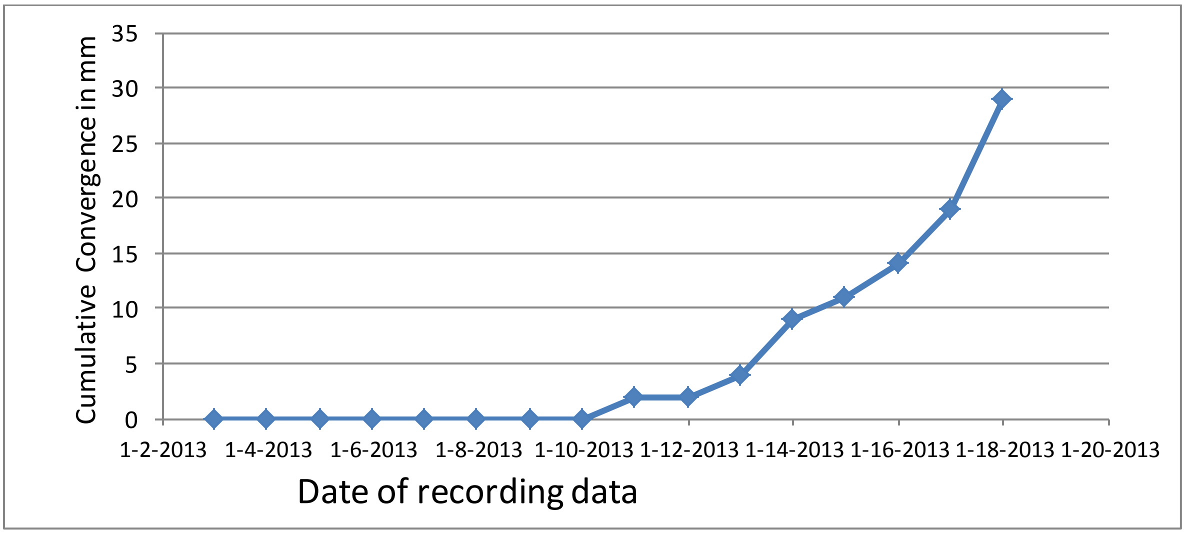
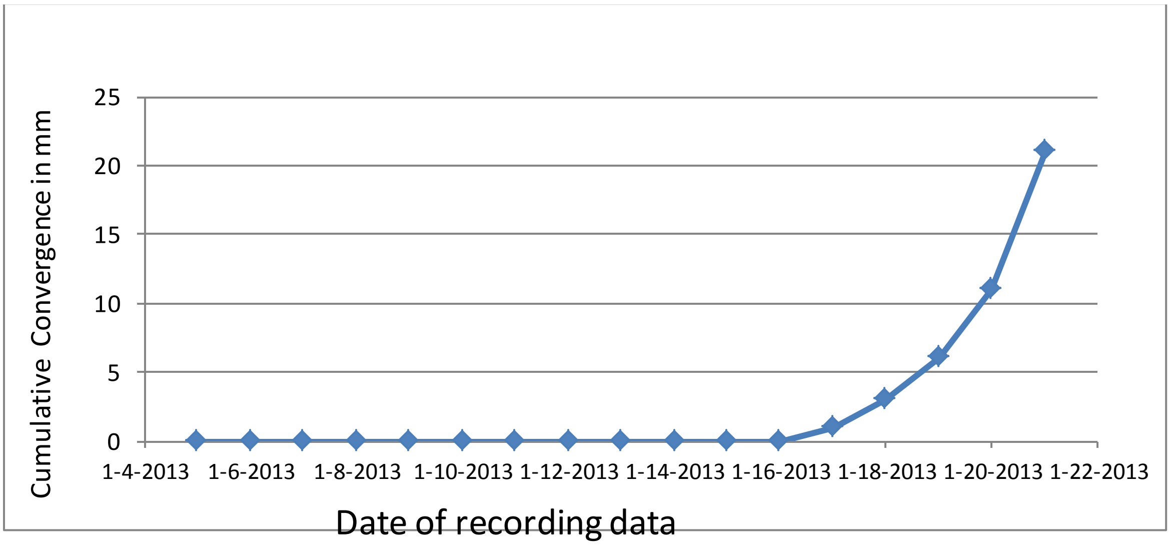


Fig 5.18: Convergence readings @ 220 m



Discussion

At the gate roads similar trends were observed as in case of the readings from the main gate. The convergence stations show a regular increase in convergence readings as the longwall face gets closer to the convergence measuring station. The convergence readings varies from 20mm-35mm at all convergence stations before they are disturbed by the retreating longwall face. The convergence readings recorded at the gate roads are considerably less than the readings collected from the main road as the influence of the strata load is far higher at the main road compared to the gate road. The maximum convergence of 42mm at gate road was recorded at convergence station at 150m.

5.6 Front and Rear Leg Pressure Observations

The front and rear leg pressure of the chock shields is noted and the graphical representation of the leg pressures as the progress of the face is demonstrated below:

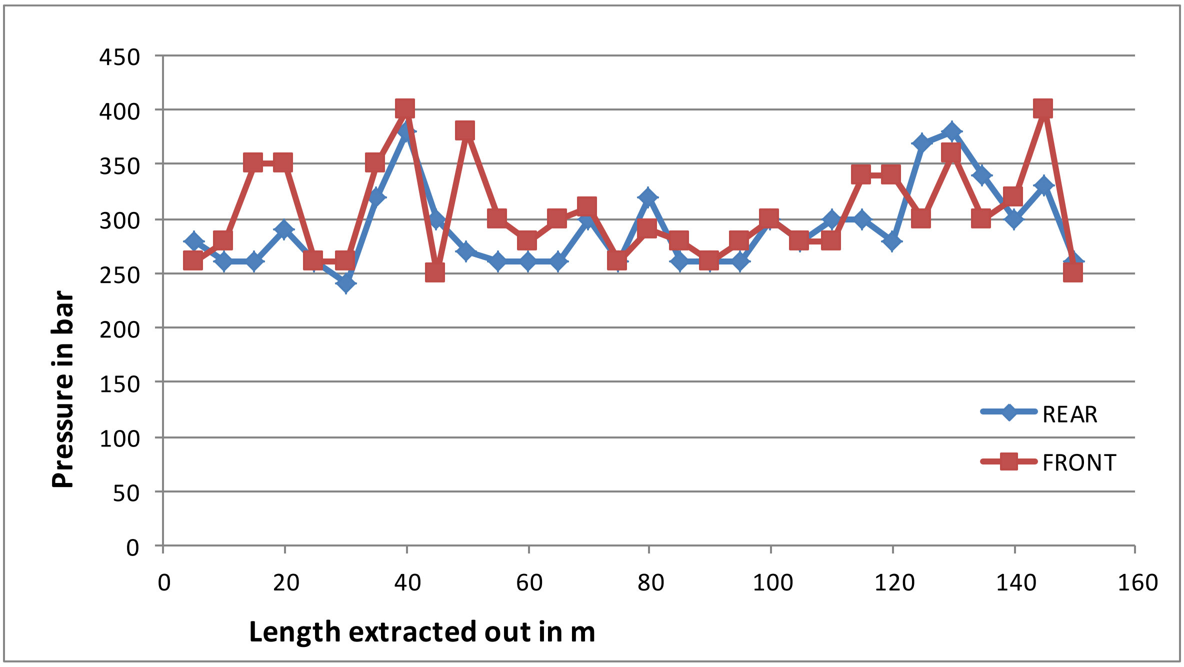


Fig 5.19: The plot shows that the distribution of load over the front legs will always be more than the load over the rear legs of the chock shield support along the face.

Discussion

It was observed that the pressure on rear leg of chock shield was less than the pressure on the front leg in every reading recorded at the face. When the load in the front leg is higher than the rear leg, the vertical stress distribution on the front portion of the canopy is the largest and the horizontal force acts towards the face, which implies a stable roof and strata condition. Maximum and minimum pressure readings at both legs were observed to occur at an interval of 30m implies roof falls in the goaf area.

5.7 Chock Shield Pressure Readings along the Face:

To study the load variance of the chock shields on the face. The total 101 chocks present at the face are divided into 3 sections and one particular chock is selected from each of the sections to demonstrate the change in load across the face

Table 5.2 : The pressure readings of chock shield supports along length of extraction

Extracted out length (in m)	Chock No 24 (Pressure in bar)	Chock No 48 (Pressure in bar)	Chock No72 (Pressure in bar)
5	250	320	260
10	280	380	280
15	220	280	260
20	260	290	260
25	250	260	240
30	300	340	260
35	320	360	280
40	240	260	250
45	270	280	260
50	230	260	250
55	270	280	260
60	230	260	200
65	240	280	260
70	250	250	300
75	260	300	200
80	280	380	260
85	250	280	240
90	250	320	260
95	260	340	260
100	280	340	260
105	300	340	260
110	250	270	240
115	250	270	240
120	250	270	240
125	250	340	260
130	280	290	260
135	300	320	300
140	280	300	280
145	300	340	290

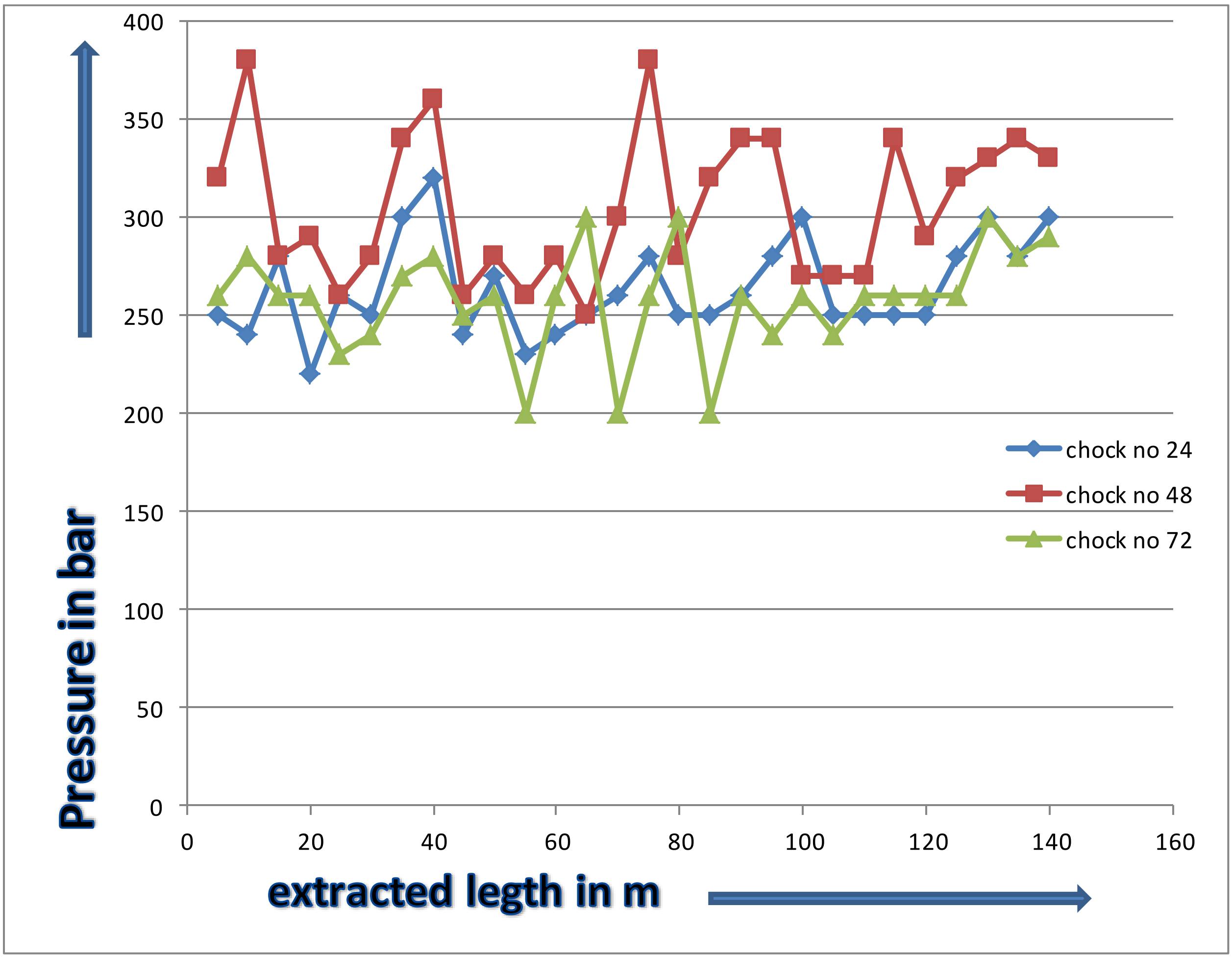


Fig. 5.20: Graph showing the pressure distribution on chock shield supports along extraction.

Discussion:

It was observed from the graph that the load experienced by the middle section of the longwall face is more than the load experienced by the other sections. The maximum pressure recorded on the chock shield was 380 bar, at chock no 48 after 10m of extraction from the longwall panel. There is a decrease in pressure observed after every 30m of extraction indicating a roof fall at such intervals. Decrease in pressure is observed at intervals of 30m indicating roof falls taking place in the goaf regions of the panel.

5.8 Numerical Modeling Design

The longwall panel has been modeled using FLAC5.0 with face length of 150m and length of panel of around 250m. At face chock shield support has been simulated with load specification of 4x 800 tonnes. The longwall panel is simulated to plot their vertical displacement and vertical stress contours over face. It shows different stages of a extraction process.

The sequence of Numerical modeling includes the following stages:

Stage 1. Longwall panel is developed in the seam.

Stage 2. Initial cut is made so as to install the machinery at the face of the panel.

Stage 3. 15m of the panel is extracted and is simulated.

Stage 4. 30m of the panel is extracted along the length of the panel and readings are noted.

Stage 5. 45m of the panel is extracted along the length of the panel and readings are noted..

Stage 6. 60m of the panel is extracted along the length of the panel and readings are noted..

Grid generated to simulate the model was presented below for different stages of extraction.

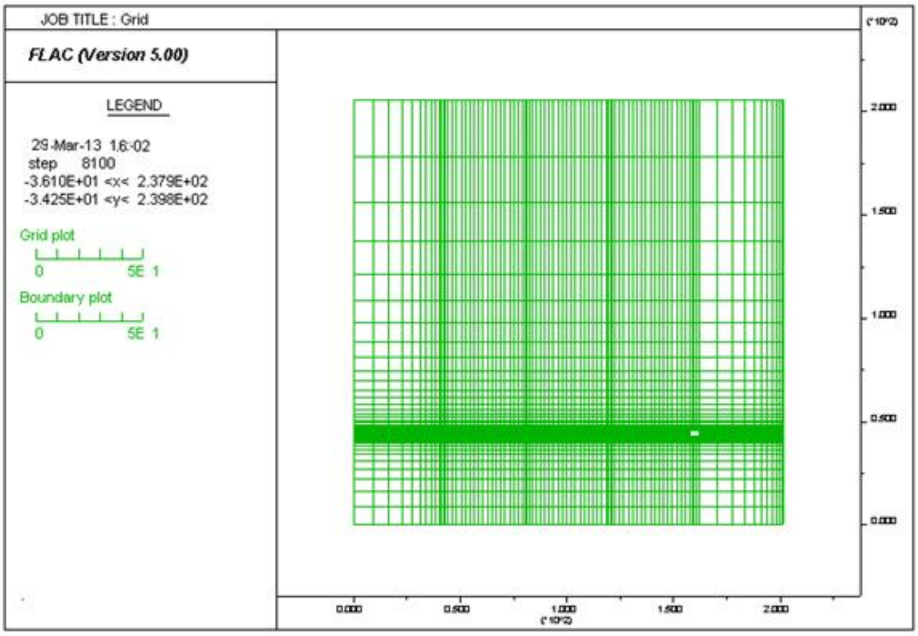


Fig 5.21: Grid generated in FLAC 5.0 for the extraction done for the initial machinery setup

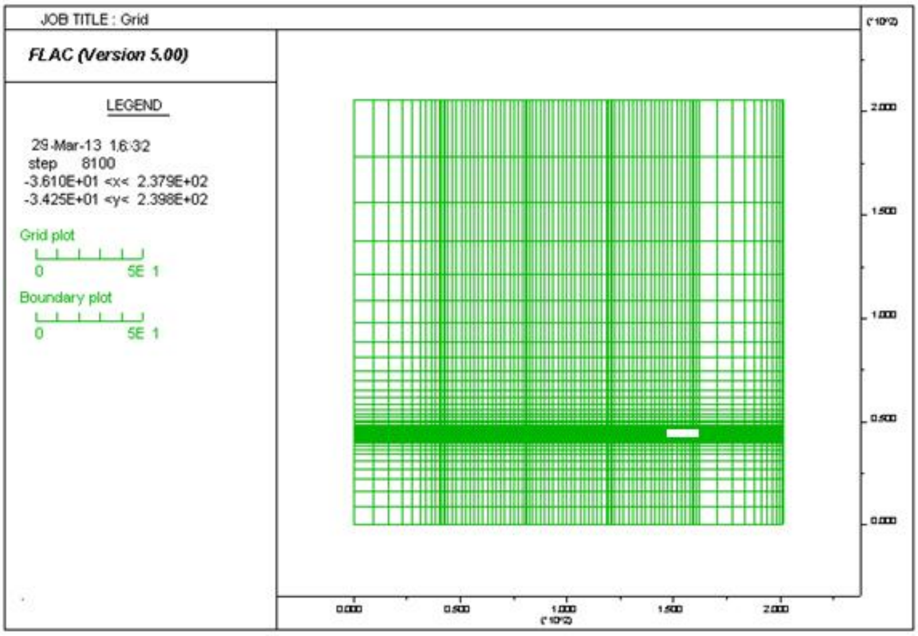


Fig: 5.22: Grid generated to simulate 15 m of extraction along the long panel.

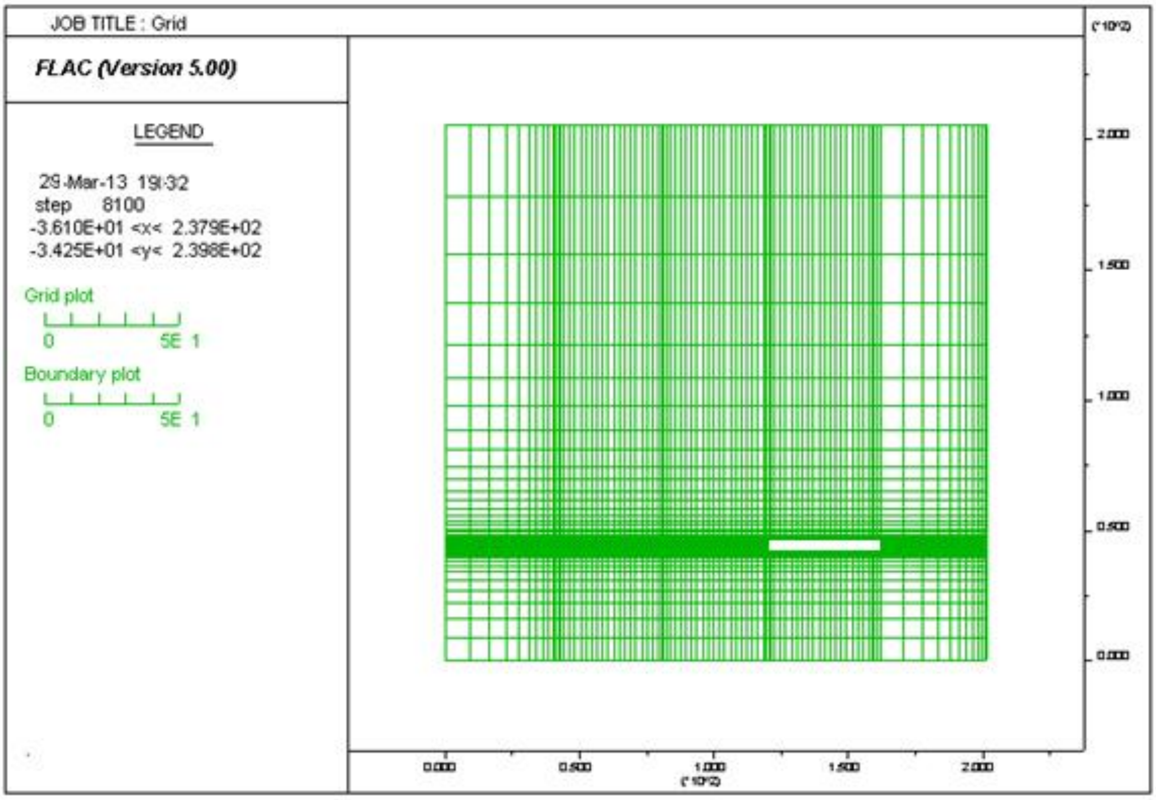


Fig: 5.23: Grid generated to simulate 30m of extraction along the longwallpanel.

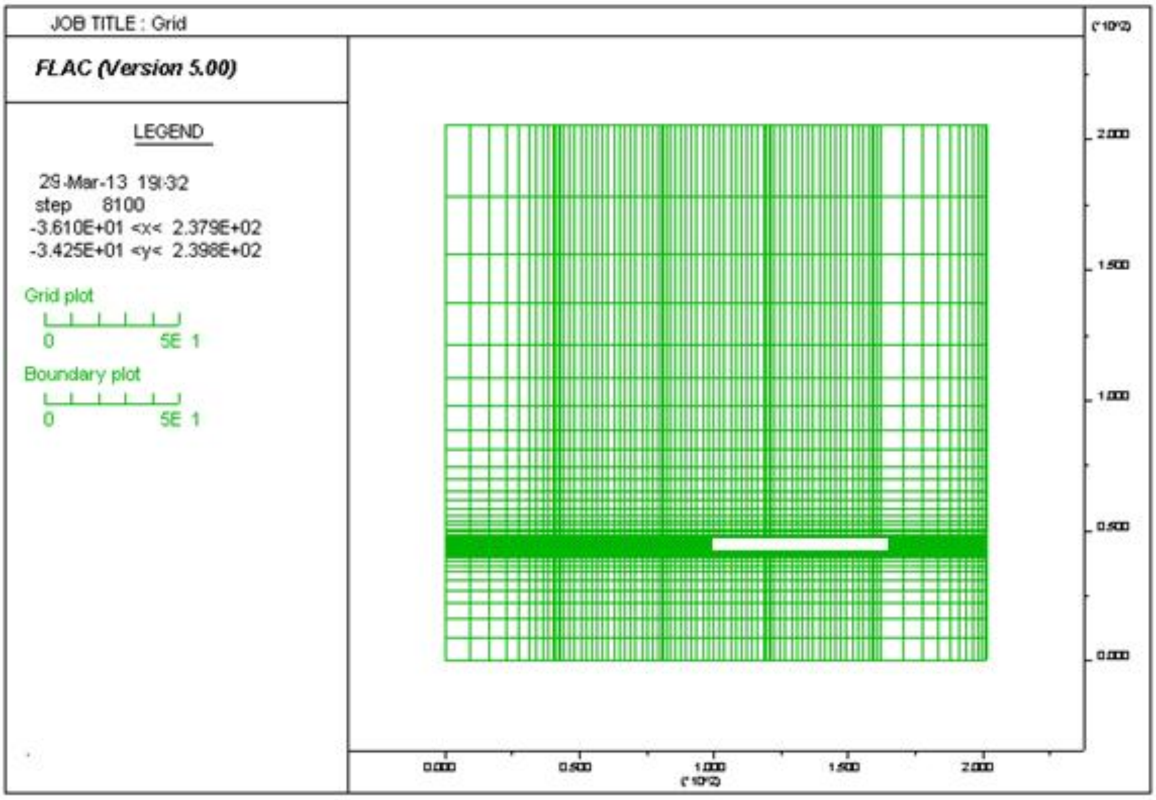


Fig: 5.24: Grid generated to model 60m of coal extraction along the longwall panel.

CHAPTER 6

RESULTS

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ANALYSIS

6. RESULTS

Numerical Modeling was done to understand the strata behavior patterns and stability of the longwall workings. The extraction of the seam is demonstrated at each interval of 15m. The extraction along with its stress and vertical sag is calculated from the models. The whole seam was considered to be 450m wide and face length was considered to be 150m.

The depth of the mine is 250m

The Chock Shield parameters are given to be:

Compressive strength: 9.7MPa

Stiffness: 0.5 mm/ton

Setting Pressure: 300 bar

Yielding Pressure: 450 bar

With the above parameters the simulation was done to get the vertical stress, horizontal stress and the roof sag over the face after extraction.

6.1 Numerical Modeling Outputs : Convergence

The deformation or the roof sag at the face of extraction is simulated and the following results are obtained.

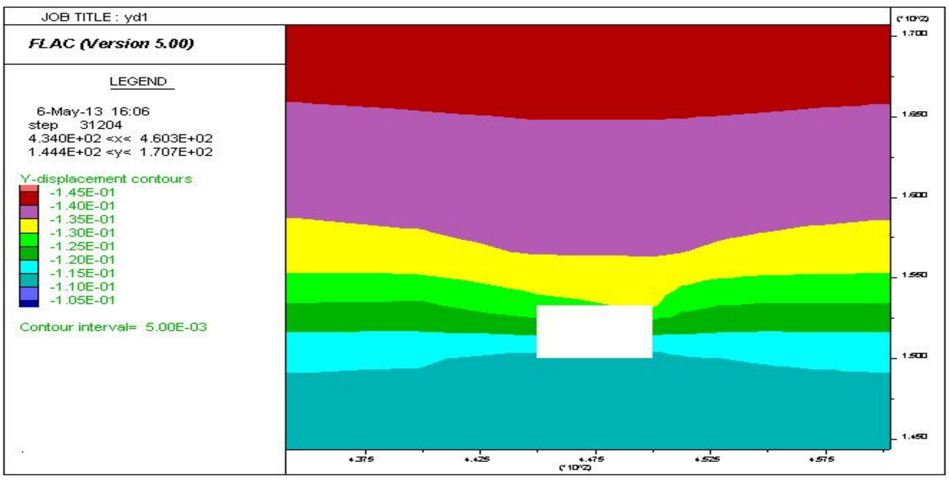

Fig. 6.1 Maximum Deformation of Roof at face at the longwall opening.

The maximum deformation noted at the face is 5 mm as derived from the numerical model. As the initial extraction has the width of 5m and the presence of chock shield supports at the face results in very less deformation at the face.

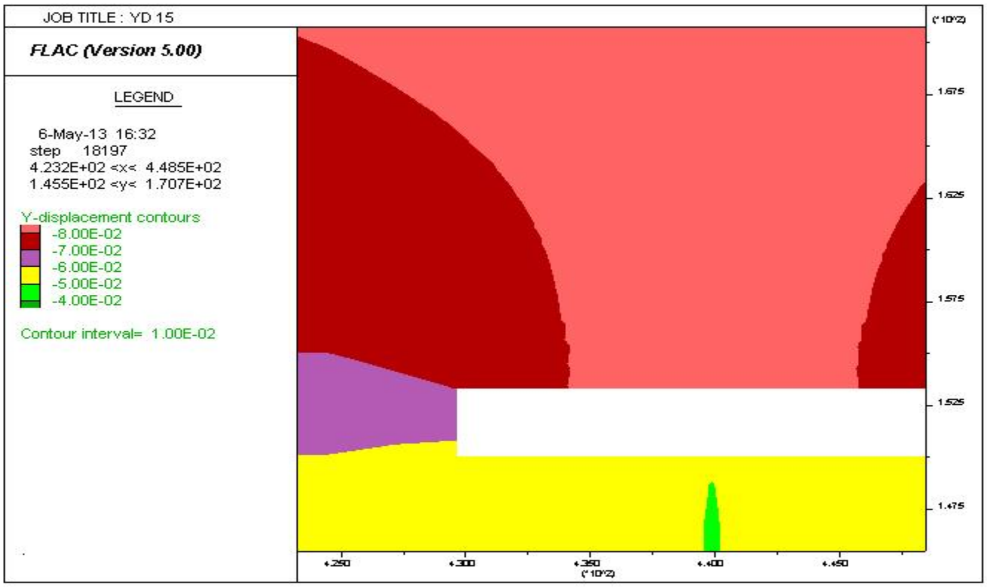

Fig 6.2 Maximum roof deformation at face after extraction of 15m

The maximum deformation registered at the face is 7 mm as is derived from the numerical model. The extraction has just started and the extracted length is just 15m so not a very deformation can be noted at the face.

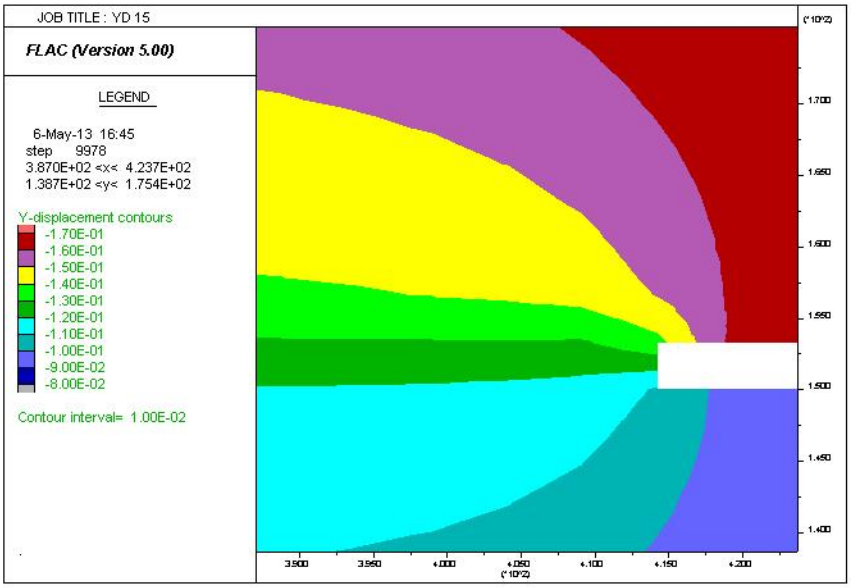

Fig. 6.3 Maximum roof deformation at face after extraction of 30m

The maximum deformation noted at the face is 15 mm as is derived from the numerical model. There is a increase in the deformation reading as the 30 m of coal has been extracted and with the increasing pressure at the face there is a larger deformation recorded at the face.

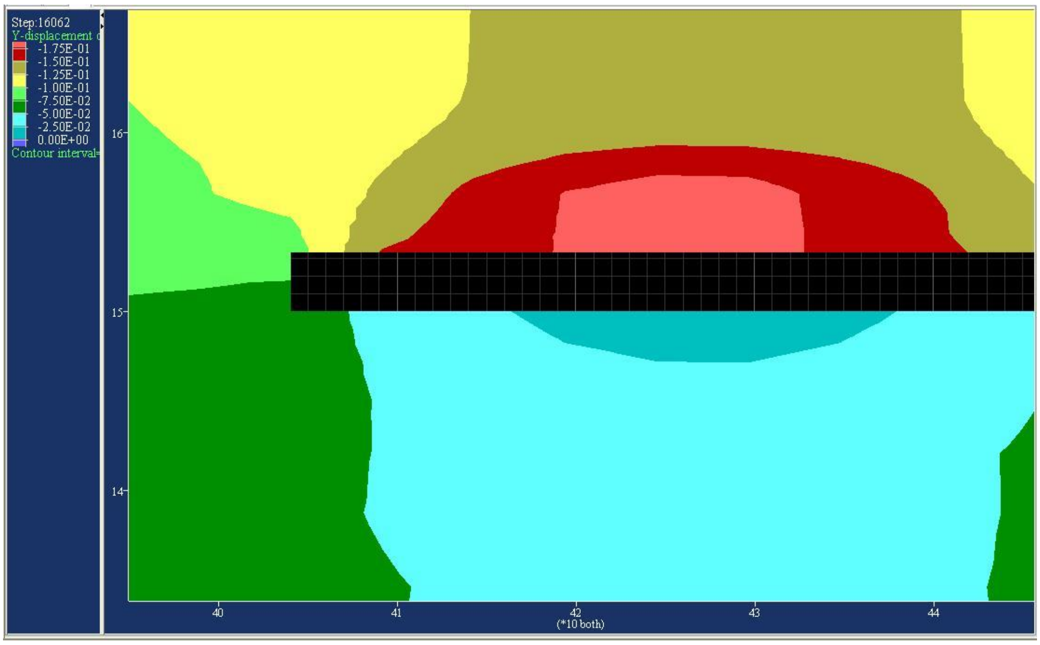

Fig. 6.4 Maximum roof deformation at face after extraction of 45m

The deformation at the face recorded after 45m of extraction is a maximum of 17mm. The chock shields are under greater load as no major fall is being recorded at the goaf which results in a greater deformation at face.

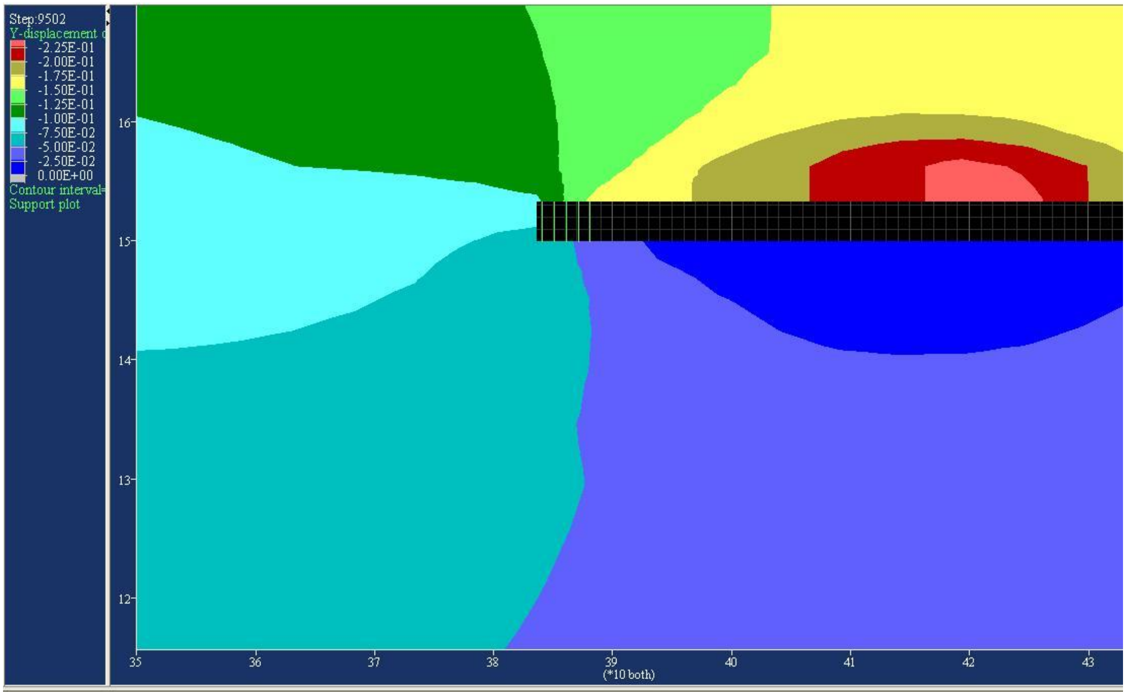

Fig. 6.5 Maximum roof deformation at face after extraction of 60m

The maximum roof deformation noted at face after 60m of extraction is 20mm. The increased deformation is due to the absence of any major fall at the goaf which resulted in an extra load at the face on the chock shields resulting in a deformation of 20mm at face.

6.2 Numerical Modeling Outputs: Vertical Stress

The Vertical Stress coming onto the face of extraction is different at different position considering the extraction taking place.

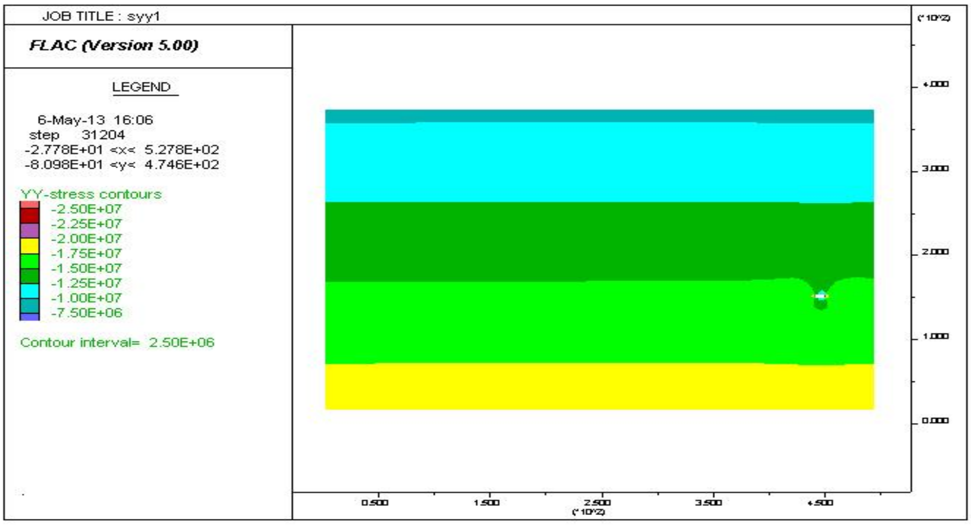

Fig 6.11 Maximum Vertical Stress In The panel After Development

The maximum stress recorded at face after the phase of development of the panel is 5MPa. At the initial development stage and with an extraction width of around 5m the vertical stress recorded is very less.

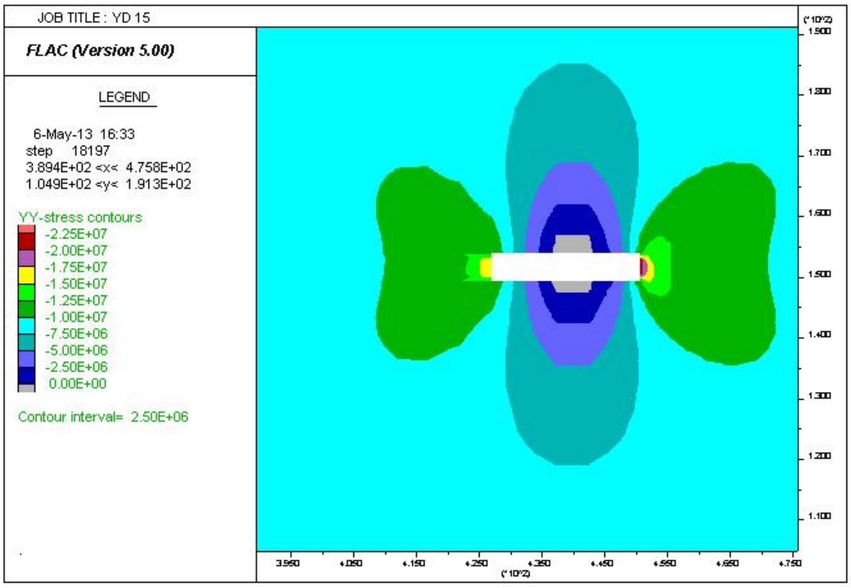

Fig. 6.12 Maximum Vertical Stress In The face after 15m extraction.

The vertical stress recorded at the face is 5.65MPa. The extracted out length is 15m as a result there is a increase in the stress recorded .

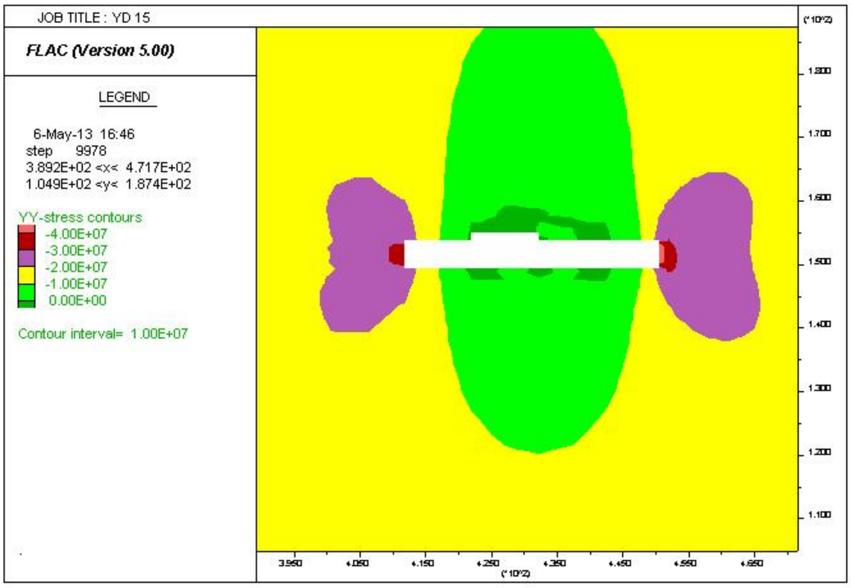

Fig 6.13 Maximum Vertical Stress In The face after 30m extraction

The maximum vertical stress recorded at 30m of extraction is 10MPa. The imideate roof over the chock shield has not experienced any major fall as a result the stress over the chock shield is more than we had observed at 15m.

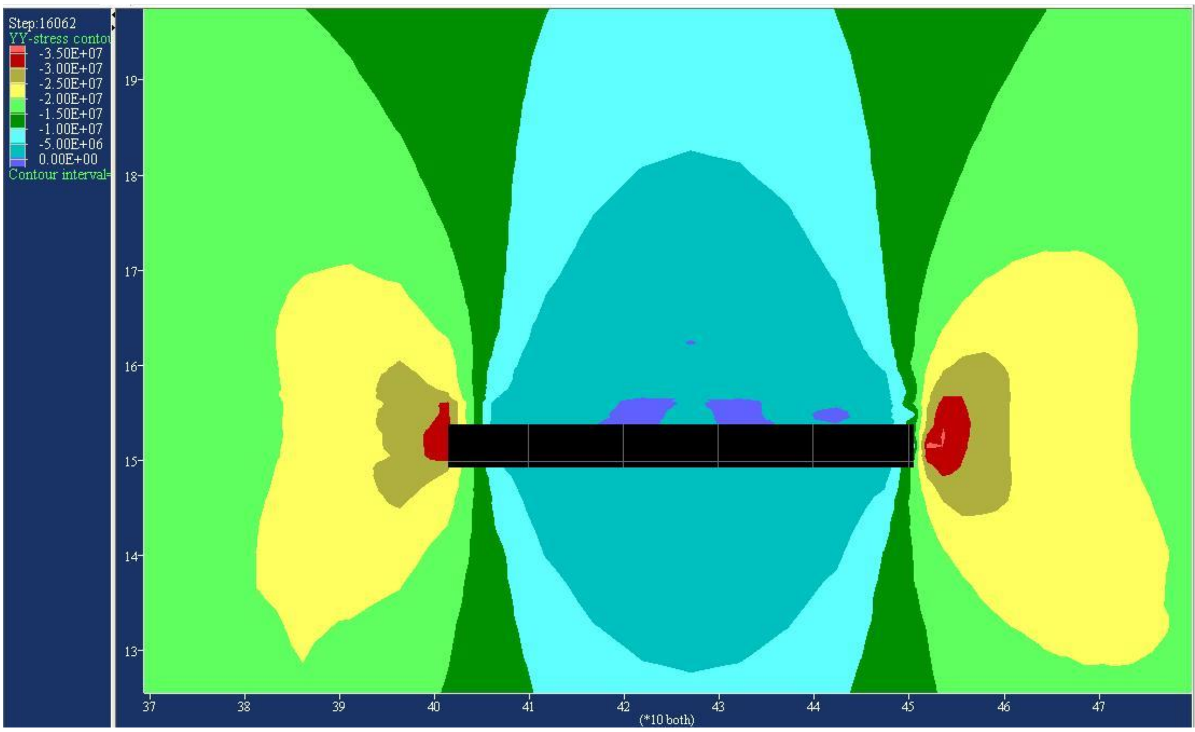

Fig 6.14 Maximum Vertical Stress In The face after 45m extraction

The stress recorded at 45m of extraction is found out to be 15MPa. The roof load has increased considerably from the last time as the face has retreated more and no major fall has been experienced in this interval.

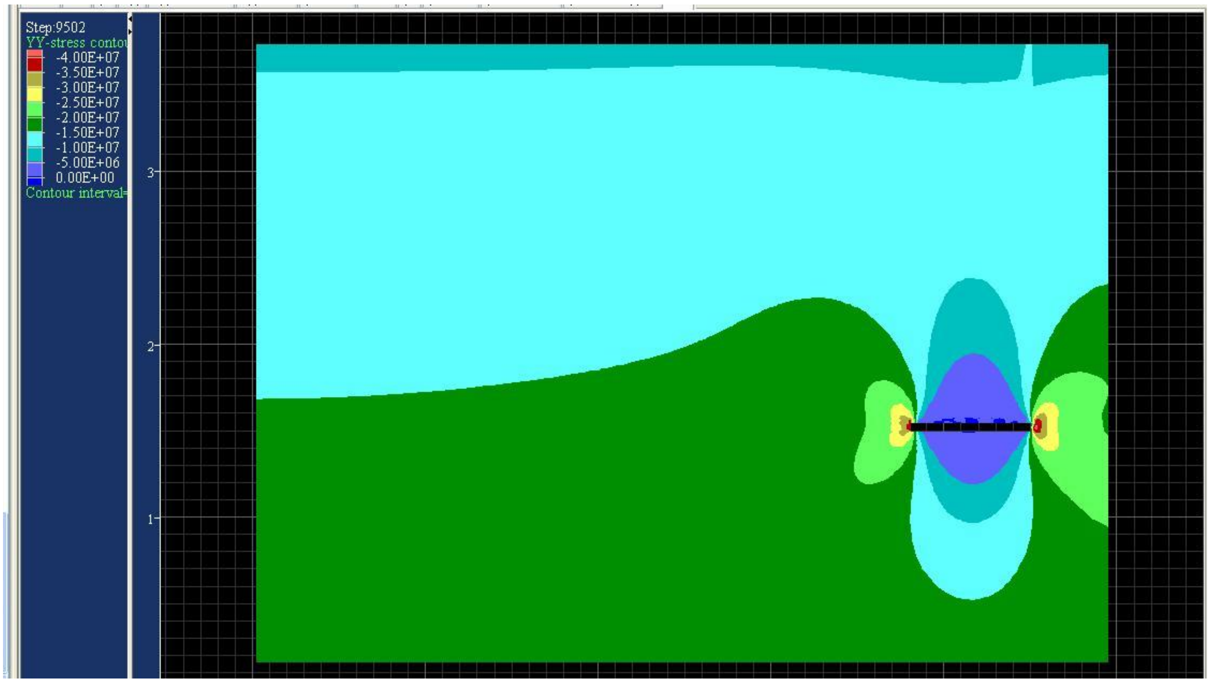

Fig 6.15 Maximum Vertical Stress In The face after 60m extraction

The maximum vertical stress recorded by the software at 60m of extraction is 25MPa. Such an high value of vertical stress as well as deformation is noted at this stage is because of the increased load over the immediate roof because no fall of the roof has taken place in the goaved out region left behind by the retreated longwall face.

CHAPTER 7

VALIDATION OF MODEL

7. VALIDATION OF MODEL

7.1 Comparison of Modeling Results with Field Investigation Data

The Numerical modeling results were compared with that of the field observations. The various stages of extraction are considered on the x axis whereas the deformation in the face with data from and data from model are plotted along the y axis.

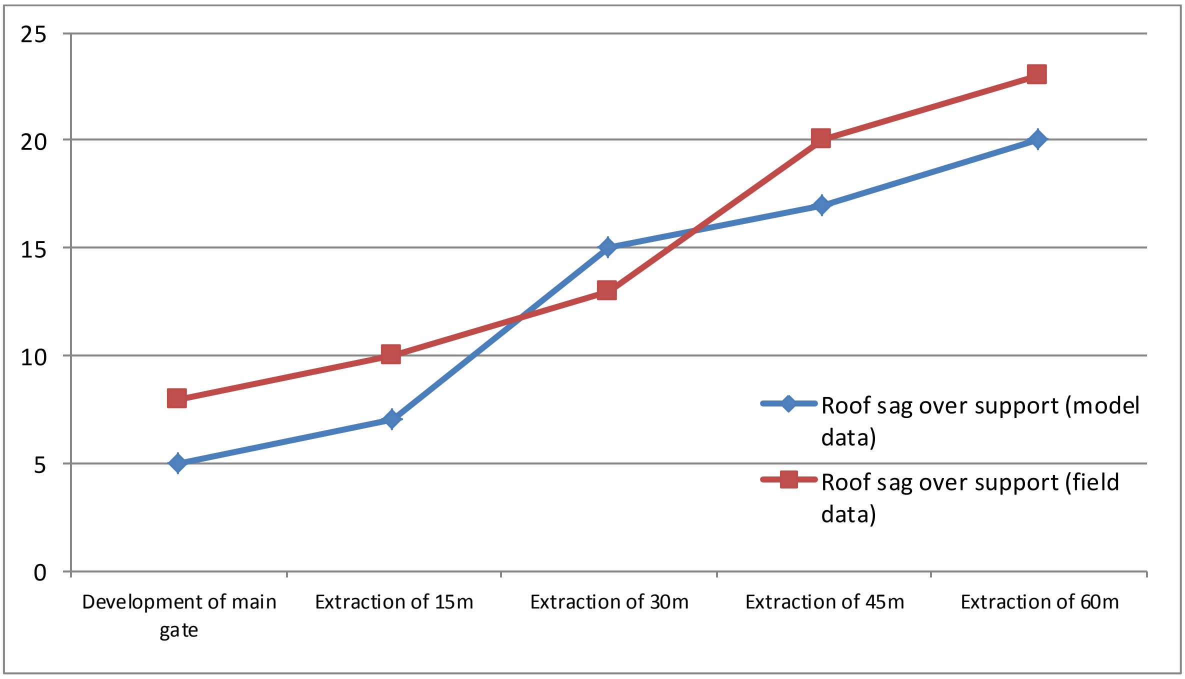

Fig.7.1 Convergence Results: FLAC Results vs. Field Investigation Data

Table 7.1 FLAC Results vs. Field Investigation Data

Stage	**Roof sag over support (model data)**	**Roof sag over support (field data)**	**Vertical stress over face**
Development of main gate	5mm	8mm	5.0MPa
Extraction of 15m	7mm	10mm	5.62 MPa
Extraction of 30m	15 mm	13mm	15MPa
Extraction of 45m	17mm	20mm	20MPa
Extraction of 60m	20mm	23mm	25 MPa

7.2 Analysis

The results collected from the simulated models of the mine show a increase in deformation as the face retreats more and more and such a similar trend has been noticed at the vertical stress recorded due to retreat of the longwall face.

The lack of any major fall can be accounted for as one of the main reasons for the increasing trends in the load and deformation values. As there is no fall taking place in the goaf region left over by the retreating longwall panel, the abutment loading on the face results in increasing values of deformation.

The gradual trend being observed is that the model generated values were less than the actual field values due to:

1. Failure to simulate all the geological features present in the seam.
2. The deformation caused due to the vibrations generated from the shearer
3. The regular tremors experienced in underground mine workings which disturb the strata.
4. Influence of the adjoining seam workings as well as mine workings.
5. The pressure caused due to presence of water table or aquatic sources.

At 30m extraction the model generated data showed a greater deformation at the face compared to the actual field data due to influence of a minor roof fall in the goaf region caused due to a minor fault present in the region which helped in reducing the abutment loading at the face thus resulting in a lesser deformation at face at the actual mine.

CHAPTER 8

CONCLUSIONS

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SUGGESTIONS

8. CONCLUSIONS

The following conclusions can be drawn based on the observation of the field data collected as well as the output obtained from the FLAC generated models.

- With the advancement of the line of extraction and increase of area of exposure, the cumulative convergence increased significantly. The maximum roof to floor convergence of 42 mm was recorded in tail gate when the face position was at 150 m and a maximum roof to floor convergence of 62mm was recorded at main gate implying a greater load concentration over the main gate compared to the tail gate.

- The pressure of the rear leg was always less than the pressure of the front leg which implies a stable roof condition over the face of extraction.

- The chock shield leg pressure readings along the face indicate a higher pressure concentration at the middle section of the face where the maximum pressure observed was 380 bar after 10m of extraction compared to the adjoining sections. Peak pressures were recorded at distances of 10m, 40m, 80m, 105m and145m while minimum pressures were observed at 20m, 50m,70m,90m,115m and 125m.

- The model generated results show a lesser deformation compared to the actual field data with the exception of the deformation at 30m where a minor roof fall at the actual mine site resulted in a decreased deformation at the mine compared to the model generated results.

- An increasing rate of convergence and pressure were observed from the results of the simulated models as the seam is extracted with a maximum of 20mm deformation recorded at 60m of extraction indicating a major roof fall occurrence beyond 60m

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8.1 Suggestions

Based on the observation and shortcomings in the execution of this project the suggestions are as follows:

1. Setting pressure and yielding pressure should be simulated at different face positions for better accuracy of data and simulation of mine conditions.

2. Reference to major falls and the consideration of major fall conditions should also be taken into account while simulation is being done.

3. Shield support characteristics should be specified consisting of various setting and yielding parameters as well as the type of material of construction of the supports.

4. The simulation should be considered with increasing the depth of the mine which would help in understanding the feasibility of longwall mining at greater depths.

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